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Effects of Static Magnetic Field Exposure on Serum Electrolytes and Tissues Histology in Albino Rats

By

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Content

Chapter 1: Introduction

Chapter 2: Materials and methods

Chapter 3: Results

Chapter 4: Discussion, conclusion, and recommendations

Dedication

This research is dedicated to:

My mother

Fatima Mohammed

Who played a big role in educating me.

My husband

Saif Alyazl Mohammed Ali

For his patience while, I was busy doing this

research and his supports.

My brothers

Abed ElGadir, Mohammed

Especially Omer, Mona

For their encouragement.

My baby

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Any one

Who reads this research and tries to make use

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Abbreviations

MRI	Magnetic resonance imaging
SMF	Static magnetic field
RF	Radio frequency
T1	Longitudinal relaxation time
T2	Transverse relaxation time
ELF	Extremely low frequency
T	Tesla
Na^+	Sodium
K^+	Potassium
Ca^{++}	Calcium
M	Male
F	Female
mT	Milli tesla
HB	Hemoglobin
HCT	Hematocrit
ELF-EMF	Extremely low frequency-electromagnetic field
Cl^-	Chloride
CMF	Constant magnetic field
Hz	Hertz
DNA	Deoxyribonucleic acid

SAR	Specific absorption rate
W/Kg	Watt/kilogram
C	Centigrade
Pc	Post coitus
MHz	Mega hertz
MTB	Methylthymol blue
ISE	Ion selective electrode
H & E	Hematoxylin and Eosin

Abstract

Background: Due to the recent developments in electronic technologies, daily exposure to strong static magnetic fields (SMF) is increasing. In particular is the increasing use of magnetic resonance imaging (MRI) for medical diagnoses. The intensity of SMF used at MRI due to development of MRI systems is increasing. Such strong-SMF exposure systems have great potential to improve medical and research applications. The hitherto studies indicated that SMF causes changes in electrolytes level and tissues histology, for that we conducted this study.

Objectives: This experimental study aims to evaluate the effects of repetitive exposure to SMF on serum Na^{+}, K^{+}, and Ca^{++} concentrations, and on some tissues (brain, liver, spleen, kidney, lung, pancreas, intestine, muscle) histology in rats.

Methods: Fifty-five Albino rats were included in this study classified to 4 groups that involved 4 different protocols of exposure to SMF, and a control group. The experimental plan was based on chest X-ray follow-up protocol in pneumonia, pleural effusion and consolidation. In this protocol, the subject will be exposed to chest X-ray image on day 1, 3 and 7, then after 4 weeks from day 7. As MRI is considered to be a safe procedure compared to X-ray the regiment can use MRI instead of X-ray. Blood samples were obtained from retro orbital venous sinus on day 1, 3, 7, and after 4 weeks from day 7 after exposing the rats to SMF (1.5 T) for 1 hour , and the level of Na^{+}, K^{+}, and Ca^{++} were measured. After the experiment was completed, the rats were sacrificed and vital organs were dissected out and histologically studied.

Results: The results showed that there was an increase in serum K^{+} concentration, and a decrease in serum Na^{+} concentration in all groups. Serum Ca^{++} level fluctuated with a decrease in the groups of day 1, and after 4 weeks from day 7 of exposure, and an increase in the group of day 3.

The histology of the vital organs of rats exposed to SMF showed necrosis, hemorrhage, and congestion of liver cells. Congestion, and

hemorrhage in renal medulla and cortex, and congestion, hemorrhage and emphysema in lungs were observed. In addition, congestion and sloughing of epithelial villi in intestine, congestion and hemorrhage in spleen were observed also. Moreover, vaculolation, and degeneration of brain cells, congestion and degeneration of muscle fiber, and degeneration of pancreas.

Conclusion: The obtained results indicated that MRI technique is potentially hazardous and affects electrolytes and some vital organs in experimental Albino rats. However, the effects on human have not yet been tested.

مستخلص البحث

خلفية: نسبة للتطورات الأخيرة في التقنيات الإلكترونية فإن التعرض اليومي للحقول المغنطيسية الساكنة القوية في ازدياد. خير مثال لذلك هو الاستخدام المتزايد لتقنية الرنين المغنطيسي في التصوير الطبي. ونسبة لتطور أجهزة الرنين المغنطيسي فأن استخدام الحقول المغنطيسية الساكنة قد زاد بصورة مكثفة. وقد كان لهذه الحقول الأثر الكبير في تحسين مستوي الاستخدامات الطبية و البحثية. أشارت الدراسات السابقة في هذا المجال أن الحقول المغنطيسية الساكنة تسبب تغيرات في مستوي الاليكترولايت والأنسجة ولذلك أجري هذا البحث.

الأهداف: الهدف من هذه الدراسة هو تقويم الآثار الناتجة عن التعريض المتكرر للحقول المغنطيسية الساكنة علي تركيز عناصر الصوديوم و البوتاسيوم و الكالسيوم وعلي بعض الأعضاء الحيوية في الفئران.

الوسائل: شملت الدراسة عدد (55) فأرا من نوع البينو وتم تصنيفها على أربعة مجموعات تعرضت إلى أربعة بروتوكولات (أنظمة) مختلفة للتعريض للحقول المغنطيسية الساكنة بالإضافة إلى مجموعة الضبط. وقد قامت خطة التجربة على نظام تتبع صور الصدر في حالات الالتهاب الرئوي والانصباب الرئوي والتصلب الرئوي وحسب هذا النظام فأن المريض (الفأر) يتعرض إلى أشعة سينية للصدر في اليوم الأول واليوم الثالث واليوم السابع ثم بعد مرور أربعة أسابيع من اليوم السابع. تم اخذ عينات الدم من الجيوب الوريدية خلف العين في اليوم الأول واليوم الثالث واليوم السابع ثم بعد أربعة أسابيع من اليوم السابع بعد تعريض الفئران إلى حقول مغنطيسية ساكنة لمدة ساعة. تم قياس مستويات تركيز عناصر الصوديوم و البوتاسيوم و الكالسيوم وبعد انتهاء التجربة يتم التخلص من الفئران بعد استخراج الأعضاء الحيوية لدراسة أنسجتها.

النتائج: أوضحت النتائج أن هناك زيادة في تركيز عنصر البوتاسيوم ونقصان في تركيز عنصر الصوديوم في كل مجموعات البحث. بينما كان هناك تذبذب في تركيز

الكالسيوم بوجود نقصان في عناصر المجموعات في اليوم الأول و اليوم الأخير(بعد أربعة أسابيع من اليوم السابع). وزيادة في مجموعة اليوم الثالث.

أوضحت دراسة نسيج الأعضاء الحيوية للفئران التي تعرضت للحقول المغنطيسية الساكنة وجود نخر ونزيف و احتقان في خلايا الكبد ووجود احتقان ونزيف في قشرة ولب الكلي وكذلك وجود احتقان ونزيف وانتفاخ في الرئتين واحتقان ونزول في النسيج الظهاري للأمعاء واحتقان ونزيف في الطحال وتأكل في الفراغات والخلايا الدماغية واحتقان وتأكل في الألياف العضلية و تأكل في خلايا البنكرياس.

الخلاصة: أوضحت النتائج المتحصل عليها خطورة تقنية الرنين المغنطيسي وأثارها الضارة علي الالكتروليتات وبعض الأنسجة الحيوية. إلا أن هذه الدراسة لم تتناول هذه الآثار علي الجنس البشري.

List of tables

List of figures

Chapter One

1.Introduction

1.1 General introduction:

Exposure to electromagnetic fields occurs everywhere: at home, work, in school, etc. Wherever there are electric wires, electric motors and electronic equipment, electromagnetic fields are created. Over the past two decades, there has been increasing interest in the biological effects and possible health outcomes of weak, low-frequency electric and magnetic fields. Epidemiological studies on magnetic fields and cancer, reproduction and neurobehavioral reactions have been presented. More recently, neurological, degenerative and heart diseases have been reported to be related to such electromagnetic fields (1).

Clinical magnetic resonance imaging (MRI) was introduced in the early 1980s and has become a widely accepted and heavily utilized medical imaging technology. This technique requires that the patients under study to be exposed to an intense magnetic field of strength not previously encountered on a wide scale by human (2).

With the growing number of operating Magnetic Resonance Systems in clinical practice, safety aspects gain increasing importance. Therefore, it is necessary to evaluate the possible risks and effects on human health (3).

This study will investigate the effects of exposure to static magnetic filed (SMF) on serum electrolytes (sodium, potassium, calcium) concentration and some tissues (brain, liver, spleen, kidney, lung, pancreas, intestine, muscle) histology in rats.

1.2 Basic physical principles of MRI:

The human body is a chemical composition of several elements such as hydrogen, carbon, nitrogen, etc. in various chemical combinations. It has been observed that the atoms of some of these elements have odd number of protons in their nuclei, and posses' magnetic properties. The magnetic properties of the protons of these elements have been utilized to produce magnetic resonance signals and images. The most abundant of these present in human body are the protons of hydrogen atom in the form of water and other various organic compounds (4).

MRI is based on electromagnetic effects of rotating protons in hydrogen of water and organic materials. With a magnetic field and high frequency electromagnetic pulses, MRI generates data sets to be reconstructed as two-dimensional cross-sectional images or three-dimensional volumes of anatomic structures with excellent soft-tissue contrast (5).

When a patient is placed in the strong magnetic field in the MRI scanner, the hydrogen nucleus align with the applied external magnetic field when exposed to short burst of electromagnetic energy in form of radio-frequency (RF) pluses. The hydrogen nuclei in the patient's body absorb its energy and then generate MR signal. This process of absorbing energy is known as magnetic resonance. It forms the basics of MRI (4).

Different amounts of "free" water result in various image characteristics. Typically, a higher tissue water content is represented by high MR signals, e.g. in blastomas, inflammations and degenerative changes. Waterless structures such as calcification or fibrous tissues, tendons and ligaments show low MR signals. Fatty structures have high signals; proteins dissolved in "free" water change the water signal dramatically. MRI is not associated with ionizing radiation and allows imaging in all planes without changing the patient's position. Disadvantages of MRI are high costs and low availability. Future technical developments will result in shorter imaging

times and broadening of the application spectrum, leading towards "MR fluoroscopy" and MR interventions (6).

1.3 Electromagnetic field types:

Three different types of electromagnetic fields are utilized in creating magnetic resonance image:

1. The static magnetic field Bo, which aligns the proton spins and generates a net magnetization vector M in the human body.

2. The gradient magnetic field, produces different resonant frequencies for aligned protons, depending on their spatial positions on the gradient axes; these gradient fields allow for the spatial localization of bi-dimensional MRI slices and hence the reconstruction of three dimensional MRI images.

3. The radio-frequency electromagnetic wave, centered at the proton resonant frequency, which rotates the vector M out of the direction of the static magnetic field; the time during which the magnetization vector returns to the equilibrium is different for each tissue, and this results in the two main imaging parameters, T_1 and T_2, which directly relate to the image contrast.

These three fields are essential features of MRI procedures, and each interacts with the electromagnetic properties of biological tissues (7).

1.4 Electromagnetic field and health outcome:

The rapid development of science and technology exposes living organisms to a wide range of electromagnetic fields. Some life-style and occupational conditions are associated with a level of electromagnetic fields higher than average. A series of epidemiological studies has raised concern about possible cancer risk of electromagnetic fields generated by power lines and electrical appliances (8).

Research on extremely low frequency (ELF) fields has been performed for more than two decades, and the methodology and quality of

studies have improved over time. Studies have consistently shown increased risk of childhood leukemia associated with ELF magnetic fields, whereas ELF fields most likely are not a risk factor for breast cancer and cardiovascular disease. There are still inadequate data for other outcomes. More recently, focus has shifted towards RF exposures from mobile telephones. There are no persuasive data suggesting a health risk, but this research field is still immature with regard to the quantity and quality of available data. This technology is constantly changing and there is a need for continued research on this issue. Almost no epidemiologic data are available for static fields (9).

1.5 MRI safety:

Safety issues and discussions about potential hazards associated with (MRI) systems and procedures have been extremely controversial over the past decade. This is due to the disputed assertions about the role of electromagnetic fields in carcinogenesis or the promotion of abnormalities in growth and development. The assumption that MRI was inherently a safe procedure had reduced the importance of the publication of negative results. Since the introduction of MRI as a clinical modality in the early 1980s, more than 100,000,000 diagnostic procedures (estimated) have been completed worldwide, with relatively few major incidents (7).

The recent development of superconducting magnets has resulted in a huge increase in human exposure to very large SMF of up to several teslas (T). Considering the rapid advances in applications and the great increases in the strength of magnetic fields used, especially in MRI, safety concerns about magnetic field exposure have become a key issue (10).

The field strength of the static field in MRI has increased from 0.015 to 12 T during the last 25 years, which is about an 800-fold increase. In addition to low and high field systems 1.5-4 T, ultra-high field systems with field strengths above four T are now available for human MRI. The increase in field strength creates the need for a better understanding of the safety challenges to ensure safety for human imaging applications. This

encompasses understanding the effects of the strong magnetic field at the atomic and molecular level and from biological tissue to organ systems. In addition to the effects of a SMF, the effects of RF and gradient-fields have to be considered (11).

Experience from previous application of ultra high field MRI indicates that transient phenomena, such as vertigo, nausea, metallic taste, are more frequently observed. In particular, movements in the field or the gradient of the fringe field seem to lead to detectable effects. Besides such observations, there is a strong demand for systematic investigation of potential interaction mechanisms related to static field exposure during MRI examinations (12).

Although generally considered safe, MRI has a number of safety issues, including the effects of high magnetic fields and RF pulses on the body and on implanted devices, the side effects of contrast agents, and toxicity during pregnancy, claustrophobia, and hearing loss (13).

However, several of the MR components (magnetic field, gradients, RF pulses, electrodes...) may cause some inconveniences to patients, most of them being reversible. However, severe accidents have been reported. Even though screening of patients for MR imaging eligibility is performed to identify patients with contra-indications to MRI, the lack of vigilance or the ignorance of certain basic safety requirements could lead to serious adverse effects, including death (14).

In MRI, healthcare workers may be exposed to strong static and dynamic magnetic fields outside of the imager. Body motion through the strong, non-uniform SMF generated by the main superconducting magnet and exposure to gradient-pulsed magnetic fields can result in the induction of electric fields and current densities in the tissue. The interaction of these fields and occupational workers has attracted an increasing awareness (15).

There are concerns about workers repeatedly exposed to magnetic fields exceeding regulatory limits with respect to modern MRI. As a result,

there is need for an ambulatory magnetic field dosimeter capable of measuring these fields in and around the MRI scanner in order to evaluate the regulatory guidelines and determine any underlying exposure risks (16).

1.6 Trace elements:

1.6.1 Sodium:

Sodium (Na^+) is the chief electrolyte in extracellular fluid. It is important for different body functions like fluid balance, neuromuscular excitability, acid base balance, maintenance of blood osmolarity, and role in resting membrane potential, and in action potential (17).

Clinical conditions related to sodium disturbances are two major types' hypernatremia and hyponatremia. The hypernatremia may occur due to simple dehydration, diabetes insipidus, excess sodium intake, and steroid therapy (17).

The hyponatremia may occur due to diuretic medication, excessive sweating, kidney diseases, congestive heart failure, and gastrointestinal loss (17).

1.6.2 Potassium:

Potassium (K^+) is major intracellular cation. It has many functions, it influences the muscular activities, involved in acid-base balance, and it has important role in cardiac function. Certain enzymes such as pyruvate kinase require it as cofactor, and it is involved in neuromuscular irritability and nerve conduction process (17).

Clinical conditions related to potassium disturbances are two major types' hyperkalemia and hypokalemia. The hyperkalemia occurs due to anuria, tissue damage, violent muscle contraction, Addison's disease, and diabetes mellitus (17).

The hypokalemia occurs due to loss of potassium in gastrointestinal secretions (prolonged vomiting), habitual users of laxative (chronic diarrhea),

Cushing's syndrome, loss of potassium in urine (diuretics), Conn's tumour, and after steriod therapy (17).

1.6.3 Calcium:

Calcium (Ca^{++}) is an important mineral mainly found in bone and teeth. It has many functions like, calcification of bones and teeth, plays a role in blood coagulation, role in muscle contraction, excitability of nerves, neuromuscular transmission, normal excitability of heart, and permeability of gap junctions (17).

Clinical conditions related to calcium disturbances are two major types, hypercalcaemia and hypocalcaemia. The hypercalcaemia occurs due to primary hyperparathyroidism, malignancy (skeletal tumour and haematological malignancies), granulomatous diseases (eg. Tuberculosis), endocrine causes, over dosage of vitamins, and drug-induced hypercalcaemia (eg. Iatrogenic) (17)

The hypocalcaemia occurs due to hypoalbuminaemia, hypoparathyroidism, renal diseases and renal failure, other miscellaneous causes (acute pancreatitis, osteomalacia and rickets, magnesium deficiency, and iatrogenic), and neonatal hypocalcaemia (17).

1.7 Basic blood Parameters of rat compared to human:

Blood is classified as connective tissue, it can be obtained easily from the superficial veins of the body, and its analysis may give a good idea of the status of body function. In the part bellow, the physical properties of human blood will be compared to those of blood from mammal other than man (rats).

Table 1.1 Comparison between human and rat in blood volume.

Rat	**Human M**	**Human F**
45.9 (34.6-59.5) ml/kg	65.5 (45.8-77.6) ml/kg	59.0 (47.6-66.5) ml/kg

Table 1.2 Comparison between human and rat in blood parameters.

Parameters	**Rat**	**Human**
Erythrocyte count	M: 8.27 (7.36-8.93) F: 7.46 (5.98-8.37)	M: 5.4 (4.6-6.2) F: 4.8 (4.2-5.4)
Hematocrit	M: 37.5 (32.5-41.1) F: 34.5 (28.2-38.1)	M: 47 (40-54) ml/100ml F:42 (37-47) ml/100ml
Leukocyte Count	M: 9.3 (3.4-17.0) F: 6.7 (2.4-13.4)	Total: 7.5 (4.5-11.5) Neutroplil: 4.4 (1.8-7.7) Eosinoplil: 0.20 (0-0.45) Basophil: 0.04 (0-0.20) Lymphocyte: 2.5 (1-4.8) Monocyte: 0.38 (0-0.8
Platelet Count	390 (190-477)	250 (100-400)

*Erythrocyte $\times 10^{-6}$ / mm^3.

*Leucocyte and Platelet $\times 10^{-3}$/ mm^3 .

Table 1.3 Comparison between human and rat in electrolytes.

Cations	**Rat**	**Human**
Sodium	M: 149 (145-154) mmol/l F: 149 (143-154) mmol/l	145 mmol/l
Potassium	M: 6.8 (5.9-7.8) mmol/l F: 6.4 (5.5-7.4) mmol/l	4.5 mmol/l
Calcium	M: 11.7(10.8-12.7)mg/dl F: 11.6 (10.7-12.6)mg/dl	9-10.5 mg/dl

1.8 Literature review:

1.8.1 Biological effects of static magnetic fields:

The safety issues associated with exposure to SMF have been discussed for more than a century. In 1892, Peterson and Kennelly studied the effects of the exposure to the largest magnet (approximately 0.15 T). They exposed a dog and a young boy to the whole-body magnetic field, finding no positive results. About 30 years later, in 1921, Drinker and Thompson investigated possible health consequences of exposure to magnetic fields in industrial workers. They performed numerous experiments in vitro, on nerve-muscle cells, and in vivo, on living animals, and they concluded that the SMF had no significance as a health hazard (7).

Interest in the biological effects of SMF has increased with the invention of MRI at the beginning of the 80s. In the last twenty years, several studies were carried out in order to understand the potential hazards associated with exposure to a strong SMF. The majority of these studies did not report positive results, thus postulating no adverse effects for human health. In 1981, Budinger summarized the work done previous to that date, concluding that from an analysis of the vast literature on cell cultures, animals, and men, no experimental protocol was found. So when repeated by other investigators, might gave reproducible positive results (7).

Twenty years later, Schenck confirmed this and concluded his review stating that, because of the difficulty in establishing a negative conclusion, it should not be concluded that it has been proven that there are no significant biological effects of SMF. However, the steadily increasing capability to realize ever-stronger magnets gives reason to believe that such effects could eventually be established, but probably at field strengths well above those currently utilized in MRI. In a relatively recent report, no adverse biological effects were found after sub-chronic (10 weeks) exposure to a very high magnetic field (9.4 T) in adult male and female rats and in their progeny (7).

In the current literature, only some sensory effects have been found associated with exposure to SMF. There was a statistically significant ($p<0.05$) finding for sensations of nausea, vertigo, and metallic taste in subjects exposed to 1.5 and 4 T static magnetic fields, but no statistical significance was found for other effects such as headache, hiccups, tinnitus, vomiting, and numbness. A higher incidence of positive reports originated from those subjects exposed to the 4 T field. However, there was no evidence that these effects were at all harmful (7).

Few studies have reported dangerous effects for human health, but such studies have neither been confirmed nor confuted by successive work. For instance, it was reported that the auditory evoked potentials of a subject exposed to a static 0.35 T magnetic field were phase-shifted; the phase shift slowly (15 minutes) returned to normal after termination of the magnetic exposure. However, further studies did not confirm these findings (7).

Research carried out by Pacini, et al in 1999 described the effects of 0.2 T SMF generated by magnetic resonance tomography on a normal human neuronal cell culture. They observed that after 15 minutes exposure, cells showed dramatic changes of morphology, developing branched dendrites and featuring synaptic buttons. Some modifications in the physiological functions of cells were also reported (7).

1.8.2 Effects of static magnetic field on hematologic and biochemical parameters:

Chater et al (18) studied the effects of SMF exposure on hematopoiesis and biochemical parameters in pregnant rats. They exposed the pregnant rats to SMF (128 mT-1 hour/day from day 6 to day 19 of pregnancy). This induced an increase in hematocrit (HCT) level, and hemoglobin (Hb) concentration. Blood glucose level increased and insulin release decreased, leading to a diabetic-like state in pregnant rats.

Hashish et al (19) examined the effects of exposure to both SMF and extremely low frequency electromagnetic field (ELF-EMF) on some blood parameters in mice exposed for 30 days. They concluded that the counts of monocytes, platelets, peripheral lymphocytes as well as splenic total T and B lymphocytes levels was significantly decreased, and The granulocytes percentage was significantly increased.

In addition, Caroline (20) studied the blood parameters in Albino rats repeatedly exposed to magnetic field only and to both magnetic field and RF electromagnetic fields. She concluded that there was reduction in white blood cell (WBC) count, lymphocyte ratio (LYM%), absolute count of lymphocyte (LYM#), and mean corpuscular volume (MCV). Moreover, elevation in (HB), mean corpuscular hemoglobin (MCH), mean corpuscular hemoglobin concentration (MCHC), (HCT), platelet (PLT) count, large platelet ratio (P-LCR), and mean platelet volume (MPV).

Okano et al (21) examined the plasma levels of nitric oxide metabolites, angiotensin II, and aldosterone in spontaneously hypertensive rats exposed to 5 mT SMF. They concluded that exposure to 5 mT resulted in reduced plasma nitric oxide metabolities concentrations together with lower levels of angiotensin II and aldosterone in spontaneously hypertensive rats. These results suggest that SMF may suppress and delay blood pressure elevation via the nitric oxide pathways and hormonal regulatory systems.

Amara (22) investigated the effects of SMF exposure on testicular function. They exposed male adult rats to SMF (128 mT; 1 h/day for 30 days). After sacrifice, the epididymal sperm number was counted. Testosterone concentration in plasma and testis was measured by radioimmunoassay. They found that sub chronic exposure to SMF had no effect on epididymal sperm count, spermatozoa motility and genital organ weight. In contrast, SMF induced decrease of testicular and plasmatic testosterone levels.

Gorczynska and Wegrzynowicz (23) evaluated the effect of SMF on enzymes activites in rats. They exposed the rats to 0.008 T and 0.15 T; inductions influence lasting 7 weeks (7 days a week), 1 h daily. They determined that there was increase of the activity of cytoplasmatic enzymes (glutamic pyruvic transaminase, glutamic oxalacetic transaminase, lactic dehydrogenase), and decrease of cholinesterase activity and the growth of alkaline phosphatase activity in the plasma of the examined animals. The observed changes were reversible. Two months after the exposure had been stopped; the tested parameters were back to normal.

1.8.3 Effect of static magnetic field on electrolytes:

Ohata et al (24) measured ion transport through a cellulose membrane exposed to the SMF in the presence of KCl solution before and after the SMF exposure. SMF at 0.24 T significantly enhanced the rate of ion transport, especially after the first exposure ($p<0.05$), while the increased ion transport rate did not return to the initial basal level after exchange of the aqueous medium. These results suggest that an irreversible, temporal conformation change took place on the cellulose membrane or on the water bound to the cellulose surface. The accelerating effect of SMF on the ion transport seems to have occurred because of stabilized hydration layer on the cellulose surface.

Gorczynska and Wegrzynowicz (25) studied the effect of chronic exposure to SMF on Na^+, K^+, and Cl^- serum concentrations by exposure of guinea pigs to magnetic field of intensity 0.005 T-0.3 T for six weeks 1 hour a day, 7 days a week. They found that this exposure produced progressively an increase in Na^+ concentration and a decrease in Cl^- concentration in the serum. The range of observed changes depends on the duration of exposure to the magnetic field. No change in serum K^+ concentration was observed following this magnetic field exposure.

Serafin et al (26) evaluated the influence of magnetic stimulation on concentration changes of selected electrolytes in patients who are at risk of coronary heart disease. However, there was a significant increase in the

concentration of potassium and magnesium in people subjected to pulsed magnetic fields (maximum intensity 0.07 mT) for 24 days, 8 minutes twice a day.

Banaszkiewicz et al (27) studied water–electrolyte equilibrium under the influence of combined using of pulsating magnetic field of low frequency and monochromatic infrared radiation in test animals. They found that there was an increase in the potassium content, including hyperkalemia, accompanied by hyponatremia in rats treated with a pulsed magnetic field (intensity 10 mT) and infrared laser radiation for 10 days, 10 minutes once a day.

Gerasimova and Nakhil'nitskaia (28) investigated the content of potassium and sodium ions in rats exposed to constant magnetic fields (CMF) of 1000 and 4500 oersted for varying time. They found that an exposure of animals to a CMF of 1000 oersted for 1 and 24 hours did not produce significant changes in the potassium and sodium content in blood. Nevertheless, an exposure of animals to a CMF of 4500 oersted induced certain changes in the electrolyte composition of the blood. During an hour exposure, the most distinct changes were an increase in the potassium concentration. During a 3-hour exposure, the most marked change was a decrease in the sodium concentration.

Schober et al (29) investigated the influence of weak magnetic fields on female white mice electrolytes balance. Three types of magnetic fields, namely of a 50 Hz sinusoidal, a 50 Hz rectangular and a 10 Hz rectangular field have been applied, the latter mainly because of its similarity to some biologic rhythms and because some technical environments also tend to produce similar type of fields. The changes of electrolyte balance were measured after one and seven days of exposure of the animals to those fields.

The 50 Hz sinusoidal and 50 Hz rectangular type of the field showed with the exception of Ca^{++} no significant changes in the animals electrolyte balance, neither after one nor after seven days. Ca^{++} levels however were in both cases significantly lower in test animals than in controls. A one-day

exposure to a 10 Hz rectangular field significantly lowers the Na^+ and increases K^+ levels. Almost reversed results were obtained after seven days; this might indicate overcompensation, after recovery (29).

Tenuzzo et al (30) studied the bio-effects induced by exposure to 6 mT static magnetic field on Primary cultures of human lymphocytes, and mice thymocytes. They found increase of intracellular Ca^{++} ions because of 6-mT SMF exposure.

Electromagnetic fields had been reported to cause a variety of biological effects. It had been hypothesized that many of these phenomena are mediated by a primary effect on the concentration of cytosolic free calcium [Ca2+]i. Carson et al (31) investigated the effects of exposure to electromagnetic fields on [Ca2+]i in HL-60 cells. They exposed the HL-60 cells to a radiofrequency electromagnetic field, a static magnetic field, and a time-varying magnetic field, which were generated by a magnetic resonance imaging (MRI) unit. They found that a 23-min exposure to all three fields, in combination, induced a significant increase in [Ca2+]i.

Aldinucci et al (32) investigated the effect of combination static electromagnetic field (EMF) at a flux density of 4.75 T together with pulsed EMF at a flux density of 0.7 mT on Ca^{++} movement in human lymphocytes exposed to those fields for 1 h. They found clearly increases in [Ca2+]i.

1.8.4 Systemic effects of static magnetic field:

Raylman (33) evaluated the effect of prolonged exposure to a very strong magnetic field (7 teals) for 64 hour on human cancer cells. They found that this exposure appeared to inhibit the growth of three human tumor cell lines in vitro. The mechanism underlying this effect has not yet been identified, although alteration of cell growth cycle and gross fragmentation of deoxyribonucleic acid (DNA) have been excluded as possible contributory factors. They suggested that future investigations of this phenomenon might have a significant impact on the future understanding and treatment of cancer.

Strong SMF has acute effects on immune cells during cell division, while the field exposure has a minimal effect on immune cells in a nondividing phase as concluded by Onodera et al (34).

Behari and Mathur (35) investigated effect of long-term exposure of SMF on developing rats. The parameters included for observations were electrocardiogram, motor activity, and organ weights. They found that electrocardiogram of the experimental animals showed higher amplitude of R and T waves, lengthening of QT interval and a slowing down of heart rate. The survival time of the two categories of animals was not significantly different. The weights of brain, skull and ovaries found to be significantly less in experimental group, while the motor activity of the corresponding group registered an increase. They concluded that these were the stressor effects caused due to long duration of exposure to the magnetic field.

Shellock and Crues (36) studied temperature, heart rate, and blood pressure responses to high-field-strength MRI in 50 patients who underwent procedures at exposures to RF radiation above the present recommended whole-body average specific absorption rate (SAR) of 0.4 W/kg. They found that body temperature significantly increased an average of 0.2 degrees C. The highest body temperature recorded after MRI was 37.5 degrees C. There was no significant correlation between the change (before and after imaging) in body temperature and whole-body average SAR.

Changes in skin temperatures were variable, depending on anatomic site. The largest change was 3.5 degrees C, and the highest skin temperature recorded after imaging was 35.1 degrees C. There was a modest correlation between the change in skin temperatures and whole-body average SAR. Average heart rate and average mean blood pressure measured immediately before imaging were not significantly different afterward. They concluded that high-field-strength MRI at the whole-body average SAR of 0.42-1.2 W/kg studied was not associated with any temperature- or hemodynamic-related deleterious effects (36).

1.8.5 Effects of static magnetic fields on morphology and histology of some vital organs:

There have been few studies on the effects of SMF at the cellular level, compared to those of extremely low frequency magnetic fields. Past studies have shown that SMF alone does not have a lethal effect on the basic properties of cell growth and survival under normal culture conditions, regardless of the magnetic density. Most but not all studies have also suggested that SMF has no effect on changes in cell growth rate. It has also been shown that cell cycle distribution is not influenced by extremely strong SMF (up to a maximum of 10 T). A further area of interest is whether SMF cause DNA damage, which can be evaluated by determination of the frequency of micronucleus formation. The presence or absence of such micronuclei can confirm whether a particular treatment damages cellular DNA (37).

This method used by Miyakoshi (37) to confirm that (SMF) alone has no such effect. However, the frequency of micronucleus formation increases significantly when certain treatments (e.g., X-irradiation) are given prior to exposure to a 10 T (SMF). It has also been reported that treatment with trace amounts of ferrous ions in the cell culture medium and exposure to (SMF) increases DNA damage.

A significantly extended cell DNA migration was observed on brain cells of mice exposed continuously to 50 Hz, 0.5 mT magnetic fields (MF) for 2 hrs, 14 days as concluded by Svedenstal et al (38). These changes indicated that magnetic fields might have genotoxic effects in brain cells.

Lai and Singh (39) studied the cumulative effect on brain cells. The rat was acutely exposed to a 60-Hz sinusoidal magnetic field at intensities of 0.1-0.5 mT for (2 hour), showed increase in DNA single- and double-strand breaks in rat's brain cells. This effect of magnetic field exposure on brain cell DNA in the rat was further investigated by exposure to a 60-Hz magnetic field at 0.01 mT for 24 hour; which caused a significant increase in DNA

single- and double-strand breaks. Prolonging the exposure to 48 hour caused a larger increase. This indicated that the effect was cumulative.

Gorczynska and Wegrzynowicz (40) examined the morphology of cardiac muscle, skeletal muscles, kidneys, cerebellum and lung tissues in guinea pigs exposed to SMF (0.005 T) for seven weeks 1 hour a day, 7 days a week. They concluded that no morphological changes were observed.

Caroline (20) studied the histology of the vital organs in Albino rats repeatedly exposed to 1.5 T SMF. She found that there were severe hemorrhage in cardiac muscle, kidney, and liver, center lobular necrosis and congestion in the liver, and congestion of the blood vessels in bone marrow.

Buemi et al (41) investigated the cell proliferation/cell death balance in renal cells from rats. They found that there were a gradual decrease in apoptosis and proliferation and a gradual increase in cells with a necrotic morphology in renal cells exposed to a 0.5 mT SMF after 2, 4 and 6 days of exposure. They suggested that SMF might have a nephropathogenic effect.

1.8.6 Effect of static magnetic field on fertility and reproduction:

Sterility can occur in mammals if spermatogenic tissue is acutely or chronically heated to levels equal to or greater than body temperature. High-field-strength MRI has been shown to elevate tissue temperatures, particularly if high levels of RF radiation are used (42).

Shellock et al (42) measured scrotal skin temperatures in eight subjects immediately before and after MR imaging of the scrotum with a 1.5-T, 64-MHz MR scanner at mean whole-body average specific absorption rates ranging from 0.56 to 0.84 W/kg (mean, 0.72 W/kg). The average imaging time was 23 min. They found that a statistically significant increase in average scrotal skin temperature was associated with MR imaging. However, the recorded temperatures were below the threshold known to affect spermatogenesis in mammals.

No effects of 50- Hz, up to 5,0 mT magnetic fields were detected on reproduction in mice. This supports none of the associations between the field and human reproductive outcome suggested by epidemiological studies as concluded by Yasuyuki (43).

Elbetieha et al (44) studied the effect of an extremely low frequency ELF magnetic field on the fertility of adult male and female Swiss mice. They exposed adult male and female mice to a 50 Hz sinusoidal magnetic field at approximately 25 microT for 90 days before they were mated with unexposed counterparts. They concluded that there were no exposure related effects on the fertility of male or female mice. The number of implantation sites, viable fetuses, and the total number of resorptions were not significantly affected in females impregnated by males exposed to the 50 Hz magnetic field as compared with the control group. The number of implantation sites, viable fetuses and the total number of resorptions in exposed females were also not statistically different from the control group. There were no significant effects on the weights of the testes, seminal vesicles, preputial gland or body weights of males exposed to 50 Hz magnetic field. Furthermore, body and uterine weights were not affected in females exposed to 50 Hz field; however, ovarian weight was significantly increased in females exposed to the same field. They suggested that exposure of male and female mice to low frequency magnetic field had no adverse effects on fertility and reproduction in mice.

Magin et al (45) studied the effects of long-duration, high-field MRI on fetal growth and postnatal development in mice. Seven experimental groups of pregnant mice were exposed for 9 hours on day 9 and/or day 12 post coitus (pc) to magnetic fields (4 T static, 5 T/sec switched gradient, and 0.2 W/kg radiofrequency at 170 MHz) associated with MRI conditions. Two experimental groups were exposed to a combination of ultrasound (day 9 pc, 3.25 MHz, focused) and MRI-associated fields (day 12 pc). They found that no statistically significant changes in fetal growth observed in the animals exposed to only MRI or ultrasound fields. However, in the combined ultrasound and MRI-exposed group, the fetal weight and crown-rump length

were reduced. They suggested that MRI and ultrasound exposure in excess of current clinical conditions could exert biological effects if applied at sensitive stages of fetal development.

1.9 Justification:

Electrolytes concentration had been reported to be affected by exposure to low power static magnetic field (mT) in previous studies. In diagnostic practice in the Sudan, the range of static magnetic fields used in MRI machine 1.0-2 T, which is relatively high power field, and usually applied for 30 to 60 minutes. The safety of this exposure needs to be investigated. If MRI investigation is needed in a patient who had abnormalities of excitability of nervous system, heart, or muscles, a sudden change in extra cellular cations like K^+, Na^+, Ca^{++} might be a serious hazard. That is why the effects of static magnetic field of MRI machine on the level of these electrolytes should be studied. Histology of some organs in rats was reported to be affected by exposure to high intensity magnetic field of MRI machine (20). In this study, a repeated exposure protocol to static magnetic field will be used and the effects of this on some tissues histology in rats will be studied.

1.10 Objectives:

General objective:

1- To investigate safety of the exposure to static magnetic field of a range used in MRI machine.

Specific objectives:

1- To study the effects of repetitive exposure to static magnetic field on serum sodium, potassium, and calcium concentrations in rats.

2- To study the effects of repetitive exposure to static magnetic field on some tissues (brain, liver, spleen, kidney, lung, pancreas, intestine, muscle) histologicaly in rats.

Chapter Two

2. Materials and Methods

This experimental study was conducted at National Research Centre (NRC), Khartoum, Sudan between November 2007 and November 2009. Fifty-five Swiss Rodentia Albino rats were included. The study was done to investigate the effects of static magnetic field exposure on serum sodium, potassium, and calcium and some tissues histology in rats.

2.1 Materials:

2.1.1 Experimental animals:

Fifty-five healthy Swiss Rodentia Albino rats weighting (120g) and aged 4 weeks were obtained from NRC.

The rat cages have solid plastic walls and a stainless steel lid, bedding material was used on trays over the cage floor to absorb urine, and feces (wood, shredded newspaper, soft board, cotton fiber, straw and hay).

The rats were kept at temperature of 20^{o} C and 55% humidity; this was maintained by using air conditioner and fan.

The photoperiod was 12h light: 12h dark cycle.

The rats were fed a standard pellet diet (soya extract, wheat, meat extract, vitamin A, and folic acid) and were given tap water to drink.

2.1.2 Blood sample collection:

Blood samples were obtained from retro orbital venous sinus in lithium heparin tubes; sera were obtained by centrifugation and were collected in plain tubes stored at -20^{o} C until analyzed.

2.1.3 MRI machine:

Philips interna (1.5) T super conductive system (Khartoum Advanced Diagnostic Center) was used.

2.1.4 Roche 9180 Electrolyte analyzer:

Was used for Na^+, and K^+ analysis.

2.1.5 Cromatest Calcium-Methylthymol Blue (Bio system calcium kit):

Was used for Ca^{++} analysis.

Consist of:

1/ Reagent (A): Potassium cyanide 7.7 mmol/l, ethanolamine 1.5 mol/l.

2/ Reagent (B): Methylthymol blue 0,1mmol/l, hydrochloric acid 10 mmol/l, hydroxyquinoline 17 mmol/l.

3/ Standard (S) is provided ready to use.

4/ Spectrophotometer.

Sensitivity: 30 mA.dl/mg = 120 mA.l/mmol.

2.1.6 Histology apparatus:

For histological tissues study the following were used:

- Microtome.
- Microtome knife.
- Microtome wheel.
- Brush (camel's hair brush)
- Heat tissue separator.
- Forceps.
- Glass slides.
- Cover slips.
- Chemical compounds
- Mayer's heamatoxylin and Eosin.
- Oven of 60 ^{o} C (for drying slides finally)
- Containers.

- Perforated porcelain dish.

2.2 Methods:

2.2.1 Experiment design:

This experimental study consisted of four groups of rats that involved 4 different protocols of exposure to SMF, and a control group. The experimental plan was based on chest X-ray follow-up protocol in pneumonia, pleural effusion and consolidation. In this protocol, the subject will be exposed to chest X-ray image on day 1, 3 and 7, then after 4 weeks from day 7. As MRI is considered to be, a safe procedure compared to X-ray the regiment can use MRI instead of X-ray (46).

Control group:

The control group consisted of 10 normal rats matched for age and weight with the experimental groups of the rats. The blood collection coincided with the study groups on day (1, 3, 7, and after 4 weeks from day 7), and Na^{+}, K^{+}, and Ca^{++} levels were tested. The 10 rats were sacrificed at the end of experiment; the brain, spleen, liver, kidney, lung, pancreas, intestine, and muscle were dissected out and kept in formalin for histological study.

Group one:

Forty-five Swiss Albino rats were exposed to static magnetic field (1.5 T) for 1 hour in day one. Blood samples were collected from retro orbital venous sinus before and after the exposure and Na^{+}, K^{+}, and Ca^{++} levels were tested. Ten rats were sacrificed and immediately; the brain, spleen, liver, kidney, lung, pancreas, intestine, and muscle were dissected out and kept in formalin for histological study. The blood collected before exposure in this group will be considered as a self-control. The blood collection failed in two rats at this stage so they were excluded from the study.

Group two:

The 33 Swiss Albino rats (after sacrificing 10 in experiment 1) were exposed to static magnetic field (1.5 T) for another 1 hour in day 3. Blood samples were collected from retro orbital venous sinus before and after the exposure and Na^{+}, K^{+}, and Ca^{++} levels were tested. Fifteen rats were sacrificed and immediately; the brain, spleen, liver, kidney, lung, pancreas, intestine, and muscle were dissected out and kept in formalin for histological study.

Group three:

The remaining 18 Swiss Albino rats were exposed to static magnetic field (1.5 T) for another 1 hour in day 7. Blood samples were collected from retro orbital venous sinus before and after each exposure and Na^{+}, K^{+}, and Ca^{++} levels were tested. Eight rats were sacrificed and immediately; the brain, spleen, liver, kidney, lung, pancreas, intestine, and muscle were dissected out and kept in formalin for histological study. The two rats lost early in the study belong to this group.

Group four:

The last 10 Swiss Albino rats were exposed to static magnetic field (1.5 T) for another 1 hour after 4 weeks from day seven. Blood samples were taken from retro orbital venous sinus before and after each exposure and Na^{+}, K^{+}, and Ca^{++} levels were tested. The 10 rats were sacrificed and immediately; the brain, spleen, liver, kidney, lung, pancreas, intestine, and muscle were dissected out and kept in formalin for histological study.

2.2.2 Biochemical analysis:

2.2.2.1 Serum Na^+ and K^+ measurements:

2.2.2.1.1 Electrolyte analyzer measurement principle:

The 9180 Electrolyte analyzer methodology is based on the ion selective electrode (ISE) measurement values. An Ion Selective Electrode measures the potential of a specific ion in solution. This potential is measured against a stable reference electrode of constant potential. The potential difference between the two electrodes will depend upon the activity of the specific ion in solution. This activity is related to the concentration of that specific ion, therefore allowing the end-user to make an analytical measurement of that specific ion.

2.2.2.1.2 Sample measurement procedure:

1/ Sample door was opened, the prompt (introduce sample) was displayed and the pump was started to aspirate.

2/ Ampoule was holed under the probe until (wipe probe close sample) was displayed.

3/ Probe were cleaned by a lint-free tissue, and then the sample door was closed.

4/ At completion of analysis, the test results was displayed and printed.

2.2.2.2 Serum Ca^{++} measurement:

2.2.2.2.1 Calcium-Methylthymol Blue principle:

Calcium in the sample reacts with methylthymol blue in alkaline medium forming a colored complex that can be measured by spectrophotometer.

Hydroxyquinoline is included in the reagent to avoid magnesium interference.

2.2.2.2.2 Sample measurement procedure:

1/ The followings were pipetted into a labeled test tubes:

- Calcium standard 1.0 ml
- Sample 1.0 ml
- Working reagent 1.0 ml

2/ Tubes were mixed thoroughly and were left for 2 minutes at room temperature.

3/ Absorbance (A) of the standard and the sample were read at 610 20 nm against the blank. The color was stable for at least 1 hour.

2.2.2.2.3 Calculation:

Calcium concentration of the sample was calculated using the following general formula:

A sample ÷ A standard × C standard = C sample mg/dl

2.2.3 Histological analysis:

1/ Preparation of tissues:

The tissues were placed in the fixative immediately after the removal from the rat's body. This fixation is to prevent post mortem changes such as putrefaction and autolysis and also to preserve various cell constituents in as life like manner as possible and to protect hardening the naturally soft tissue, thereby allowing easy manipulation during subsequent processing. Another reason for fixation is to convert the normal semi-fluid consistency of cells to an irreversible semi-fluid consistency and to aid in the visual differentiation of structure by applications of biological dyes and chemicals. Formalin 10% was used as fixative.

2/ processing of tissue:

This was done by dehydration, clearing, impregnation and embedding.

- Dehydration was done by using isopropyl alcohol.
- The intermediate phase was done by using xylen.
- Impregnation (removal of clearing reagents) was done by paraffin penetrated the tissues by 3 paraffin baths at a melting point of 58%.
- Embedding was done by orienting the tissues in the melted paraffin to provide a firm medium when solidified to be sectioned.

3/ Preparation of sections:

After preparing sharped knife microtomes various steps in sectioning tissues were done as the following:

- Orientation of the block in the microtome.
- Soaking the icing to ensure constant temperature of both block and knife.
- Floating ribbon on floatation bath.
- Separation of sections by using a heated tissue separator with optimum degree of heating.
- Picking up sections on glass slides.
- Resealing blocks.

The sections were attached to the slides by using the gelatin adhesive (three teaspoonfuls of the 5% gelatin solution per 1000 ml in the floatation bath.

4/ Staining:

Staining was done by using Hematoxylin and Eosin (H & E stain).

After preparing slides, they were studied and diagnosed under microscope with magnification 10 and 40 by 2 pathologists to confirm the slides readings and results.

2.2.4 Statistical analysis:

The data was analyzed using the Statistical Package for the Social Sciences (SPSS) - dependent T test was used for analysis on the same groups and independent T test was used for analysis on different groups.

Chapter Three

3. Results

This study investigated the effects of static magnetic field exposure on serum Na^+, K^+, Ca^{++} and tissues histology in rats.

3.1 Serum Na^+, K^+, and Ca^{++} levels in the control group of the rats:

In the control group of the rats there were no significant changes occurred in serum Na^+, K^+ or Ca^{++} levels during the total experimental period as shown in (Table 1). Serum Na^+ (mean ± SD) was 142.15 ± 0.87 mmol/l in day 1 of the experiment, 142.26 ± 0.77 mmol/l in day 3, 141.85 ± 0.67 mmol/l in day 7, and 141.54 ± 0.45 mmol/l after 4 weeks from day 7. Serum K^+ (mean ± SD) was 5.17 ± 0.14 mmol/l in day 1, 5.11 ± 0.11 mmol/l in day 3, 5.21 ± 0.08 mmol/l in day 7, and 5.32 ± 0.13 mmol/l after 4 weeks from day 7. Serum Ca^{++} was 10.28 ± 0.20 mg/dl in day 1, 10.30 ± 0.11 mg/dl in day 3, 10.30 ± 0.11 mg/dl in day 7, and 10.29 ± 0.09 mg/dl after 4 weeks from day 7.

3.2 Serum Na^+, K^+, and Ca^{++} levels before and after exposure to static magnetic field in group one of the rats (day 1):

Serum Na^+ level in this group after exposure to SMF for 1 hour was (mean ± SD) 140.91 ± 3.74 mmol/l on comparing this with the control group (mean ± SD) 142.15 ± 0.87 mmol/l a significant difference was obtained (P=0.05) as shown in (Table 2). A significant increase in serum K^+ level was observed in this group when comparing the control group reading with after exposure reading. The (mean ± SD) 5.17 ± 0.14 mmol/l and 5.88 ± 0.63 mmol/l respectively (P=0.00) as shown in (Table 2). The mean serum Ca^{++} was 10.28 ± 0.20 mg/dl for control and 9.71 ± 0.96 mg/dl after exposure, this indicated a significant decrease in serum Ca^{++} (P=0.00) as shown in (Table 2).

Serum Na^+ level (mean ± SD) in the total number of experimental rats at the start of experiment was 141.65 ± 2.82 mmol/l, and after exposing these rats to SMF for 1 hour the (mean ± SD) was 140.91 ± 3.74 mmol/l. No change in serum Na^+ was noticed (P=0.30) as shown in (Table 3). The mean of serum K^+ was 5.12 ± 0.52 mmol/l before exposure to SMF and 5.88 ± 0.63 mmol/l after exposure to SMF for 1 hour. This indicated a significant increase (P=0.00) as shown in (Table 3). Serum Ca^{++} showed a significant decrease after exposure (mean ± SD) was 10.30 ± 1.15 mg/dl and 9.71 ± 0 .96 mg/dl after exposure to SMF for 1 hour (P=0.01) as shown in (Table 3).

3.3 Serum Na^+, K^+, and Ca^{++} levels before and after exposure to static magnetic field in group two of the rats (day 1 and 3):

After exposing the experimental rats to SMF for another hour in day 3, the mean of serum Na^+ was 140.63 ± 3.99 mmol/l. A significant decrease was noticed in serum Na^+ (P=0.03) compared to control group (mean ± SD) 142.26 ± 0.77 mmol/l as shown in (Table 4). A significant increase was noticed in serum K^+ (P=0.00). The mean after exposure was 5.56 ± 0.63 mmol/l compared to control group (mean ± SD) 5.11 ± 0.11 mmol/l as shown in (Table 4). The mean serum Ca^{++} was 10.30 ± 0.11 mg/dl for control group and 10.60 ± 0.56 mg/dl after exposure. A significant increase was noticed (P=0.00) as shown in (Table 4).

Serum Na^+ concentration ranged from 143.27 ± 3.52 mmol/l before exposure and 140.64 ± 3.99 mmol/l after exposure to SMF for another hour on day 3. This showed a significant decrease (P=0.00) as shown in (Table 5). The mean of serum K^+ was 5.42± 0.54 mmol/l before exposure and 5.56 ± 0.63 mmol/l after exposure. No significant change in serum K^+ was obtained (P=0.35) as shown in (Table 5). Also no significant change in serum Ca^{++} (P=0.88) between before and after exposure readings (mean ± SD) 10.62± 0.60 mg/dl, 10.60 ± 0.56 mg/dl respectively as shown in (Table 5).

There was no significant change in serum Na^+ (P=0.19) between initial reading of experimental group (pre-experiment reading) of 141.65 ± 2.82 mmol/l to value estimated on day 3 after exposure to anther hour 140.63 ± 3.99 mmol/l as shown in (Table 6). A significant increase was noticed in serum K^+ (P=0.00). The mean was 5.56 ± 0.63 mmol/l after exposure compared to pre-experiment reading 5.12 ± 0.52 mmol/l as shown in (Table 6). No significant change in serum Ca^{++} (P=0.174) between pre-experiment and after exposure readings. The mean was 10.30 ± 1.15 mg/dl, 10.60 ± 0.56 mg/dl respectively as shown in (Table 6).

3.4 Serum Na^+, K^+, and Ca^{++} levels before and after exposure to static magnetic field in group three of the rats (day 1, 3, and 7):

The rats were exposed to SMF for another third hour in day 7. The mean of serum Na^+ was 134.89 ± 2.60 mmol/l after exposure, which showed a significant decrease compared to control reading 141.85 ± 0.67 mmol/l (P=0.00) as shown in (Table 7). The mean of serum K^+ was 5.21 ± 0.08 mmol/l for control and 5.88 ± 0.64 mmol/l after exposure. A significant increase was noticed in serum K^+ (P=0.00) as shown in (Table 7). No significant change in serum Ca^{++} (P=0.06). The mean was 10.30 ± 0.11 mg/dl for control and 10.47 ± 0.34 mg/dl after exposure as shown in (Table 7).

The Na^+ concentration in serum was 138.11 ± 2.47 mmol/l before exposure and decreased to 134.89 ± 2.60 mmol/l after exposure to SMF in day 7 (P=0.00) as shown in (Table 8). Serum K^+ was increased from 5.17 ± 0.85 mmol/l before to 5.88 ± 0.64 mmol/l after exposure (P=0.00) as shown in (Table 8). No significant change in serum Ca^{++} (P=0.93). The mean was 10.46 ± 0.41 mg/dl before and 10.47 ± 0.34 mg/dl after exposure as shown in (Table 8).

The mean Na^+ concentration after exposing the rats to a third hour in day 7 was 134.89 ± 2.60 mmol/l compared to initial reading of the experimental group (mean ± S.D) 141.65 ± 2.82 mmol/l. A significant decrease was observed (P=0.00) as shown in (Table 9). Serum K^+ was increased from pre-experiment reading 5.12 ± 0.52 mmol/l to after exposure reading 5.88 ± 0.64 mmol/l (P=0.00) as shown in (Table 9). Serum Ca^{++} pre-experiment reading was 10.30 ± 1.15 mg/dl and after exposure reading was 10.47 ± 0.34 mg/dl. No significant change in serum Ca^{++} (P=0.16) as shown in (Table 9).

3.5 Serum Na^+, K^+, and Ca^{++} levels before and after exposure to static magnetic field in group four of the rats (day 1, 3, 7, and after 4 weeks):

After 4 weeks from day 7 when exposing the rats to the last fourth hour the mean serum Na^+ was 136.30 ± 4.59 mmol/l. On comparison with control mean 141.54 ± 0.45 mmol/l a significant decrease was noticed (P=0.00) as shown in (Table 10). mean Serum K^+ was increased when comparing after exposure reading with control, the mean was 6.02 ± 0.57 mmol/l, 5.32 ± 0.13 mmol/l respectively (P=0.00) as shown in (Table 10). Mean serum Ca^{++} was 10.29 ± 0.09 mmol/l for control and 9.80 ± 0.18 mmol/l after exposure. A significant decrease was noticed (P=0.00) as shown in (Table 10).

No significant changes were obtained when comparing before and after exposure readings for the three electrolytes. The mean of serum Na^+ was 137.10 ± 2.64 mmol/l before and 136.30 ± 4.59 mmol/l after exposure (P=0.63) as shown in (Table 11). The mean of serum K^+ was 6.12 ± 0.67 mmol/l before and 6.02 ± 0.57 mmol/l after exposure (P=0.72) as shown in (Table 11). The mean of serum Ca^{++} was 9.85 ± 0.15 mg/dl before and 9.80± 0.18 mg/d after exposure (P=0.52) as shown in (Table 11).

A significant decrease was noticed in serum Na^{+} (P=0.00) when comparing after exposure reading with the initial experimental reading. The mean 136.30 ± 4.59 mmol/l and 141.65 ± 2.82 mmol/l respectively as shown in (Table 12). Serum K^{+} was increased from 5.12 ± 0.52 mmol/l as initial reading to 6.02 ± 0.57 mmol/l after exposure (P=0.00) as shown in (Table 12). Serum Ca^{++} pre-experiment reading was 10.30 ± 1.15 mg/dl and 9.80 ± 0.18 mg/dl after exposure. No significant change in serum Ca^{++} was obtained (P=0.17) as shown in (Table 12).

Table 1: Serum Na^+, K^+, and Ca^{++} in the 4 days of the experiment in the control group of the rats (Mean±SD).

Days	Na^+ mmol/l (Mean±SD)	K^+ mmol/l (Mean±SD)	Ca^{++} mg/dl (Mean±SD)
Day one	142.15 ±0.87	5.17 ± 0.14	10.28 ± 0.20
Day three	142.26 ± 0.77	5.11 ± 0.11	10.30 ± 0.11
Day seven	141.85 ± 0.67	5.21 ± 0.08	10.30 ± 0.11
After 4 weeks	141.54 ± 0.45	5.32 ± 0.13	10.29 ± 0.09

Table 2: Serum Na^+, K^+, and Ca^{++} levels in the control group compared to group one (rats exposed to static magnetic field in day one) (Mean±S.D).

Parameters	Number of Rats (n)	Mean ± S.D	P-value
Na^+ mmol/l			
Control	10	142.15 ± 0.87	
After exposure	43	140.91 ± 3.74	0.05*
K^+ mmol/l			
Control	10	5.17 ± 0.14	
After exposure	43	5.88 ± 0.63	0.00*
Ca^{++} mg/dl			
Control	10	10.28 ± 0.20	
After exposure	43	9.71 ± 0.96	0.00*

* P is significant at ≤ 0.05

Table 3: Serum Na^+, K^+, and Ca^{++} levels immediately before and after exposure to static magnetic field in group one (rats exposed to static magnetic field in day 1) (Mean±S.D).

Parameters	Number of Rats (n)	Mean ± S.D	P-value
Na^+ mmol/l			
Before exposure	**43**	**141.65±2.82**	
After exposure	**43**	**140.91±3.74**	**0.30**
K^+ mmol/l			
Before exposure	**43**	**5.12±0.52**	
After exposure	**43**	**5.88± 0.63**	**0.00***
Ca^{++} mg/dl			
Before exposure	**43**	**10.30± 1.15**	
After exposure	**43**	**9.71±0.96**	**0.01***

* P is significant at ≤ 0.05

Table 4: Serum Na^+, K^+, and Ca^{++} levels in the control group compared to group two (rats exposed to static magnetic field in day 1 and 3) (Mean±S.D).

Parameters	Number of Rats (n)	Mean ± S.D	P-value
Na^+ mmol/l			
Control	**10**	**142.26±0.77**	
After exposure	**33**	**140.63± 3.99**	**0.03***
K^+ mmol/l			
Control	**10**	**5.11± 0.11**	
After exposure	**33**	**5.56± 0.63**	**0.00***
Ca^{++} mg/dl			
Control	**10**	**10.30±0.11**	
After exposure	**33**	**10.60±0.56**	**0.00***

* P is significant at ≤ 0.05

Table 5: Serum Na^+, K^+, and Ca^{++} levels immediately before and after exposure to static magnetic field in group two (rats exposed to static magnetic field in day 1 and 3) (Mean±S.D).

Parameters	Number of Rats (n)	Mean ± S.D	P-value
Na^+ mmol/l			
Before exposure	33	143.27±3.52	
After exposure	33	140.64±3.99	0.00*
K^+ mmol/l			
Before exposure	33	5.42±0.54	
After exposure	33	5.56± 0.63	0.35
Ca^{++} mg/dl			
Before exposure	33	10.62±0.60	
After exposure	33	10.60±0.56	0.88

* P is significant at ≤ 0.05

Table 6: Serum Na^+, K^+, and Ca^{++} levels in group two (rats exposed to static magnetic field in day 1 and 3) compared to the initial finding of the experimental group (Mean ± S.D).

Parameters	Number of Rats (n)	Mean ± S.D	P-value
Na^+ mmol/l			
Control	43	141.65± 2.82	
After exposure	33	140.63± 3.99	0.19
K^+ mmol/l			
Control	43	5.12± 0.52	
After exposure	33	5.56± 0.63	0.00*
Ca^{++} mg/dl			
Control	43	10.30±1.15	
After exposure	33	10.60± 0.56	0.17

* P is significant at ≤ 0.05

Table 7: Serum Na^+, K^+, and Ca^{++} levels in the control group compared to group three (rats exposed to static magnetic field in day 1, 3, and 7) (Mean ± S.D).

Parameters	Number of Rats (n)	Mean ± S.D	P-value
Na^+ mmol/l			
Control	**10**	**141.85±0.67**	
After exposure	**18**	**134.89± 2.60**	**0.00***
K^+ mmol/l			
Control	**10**	**5.21± 0.08**	
After exposure	**18**	**5.88± 0.64**	**0.00***
Ca^{++} mg/dl			
Control	**10**	**10.30±0.11**	
After exposure	**18**	**10.47± 0.34**	**0.06**

* P is significant at ≤ 0.05

Table 8: Serum Na^+, K^+, and Ca^{++} levels immediately before and after exposure to static magnetic field in group three (rats exposed to static magnetic field in day 1, 3, and 7) (Mean±S.D).

Parameters	Number of Rats (n)	Mean ± S.D	P-value
Na^+ mmol/l			
Before exposure	**18**	**138.11±2.47**	
After exposure	**18**	**134.89±2.60**	**0.00***
K^+ mmol/l			
Before exposure	**18**	**5.17±0.85**	
After exposure	**18**	**5.88± 0.64**	**0.00***
Ca^{++} mg/dl			
Before exposure	**18**	**10.46± 0.41**	
After exposure	**18**	**10.47±0.34**	**0.93**

* P is significant at ≤ 0.05

Table 9: Serum Na^+, K^+, and Ca^{++} levels in group three (rats exposed to static magnetic field in day 1, 3, and 7) compared to the initial finding of the experimental group (Mean ± S.D).

Parameters	Number of Rats (n)	Mean ± S.D	P-value
Na^+ mmol/l			
Control	43	141.65±2.82	
After exposure	18	134.89±2.60	0.00*
K^+ mmol/l			
Control	43	5.12±0.52	
After exposure	18	5.88± 0.64	0.00*
Ca^{++} mg/dl			
Control	43	10.30±1.15	
After exposure	18	10.47± 0.34	0.16

* P is significant at ≤ 0.05

Table 10: Serum Na^+, K^+, and Ca^{++} levels in the control group compared to group four (rats exposed to static magnetic field in day 1, 3, 7, and after 4 weeks) (Mean ± S.D).

Parameters	Number of Rats (n)	Mean ± S.D	P-value
Na^+ mmol/l			
Control	10	141.54±0.45	
After exposure	10	136.30±4.59	0.00*
K^+ mmol/l			
Control	10	5.32±0.13	
After exposure	10	6.02±0.57	0.00*
Ca^{++} mg/dl			
Control	10	10.29±0.09	
After exposure	10	9.80±0.18	0.00*

* P is significant at ≤ 0.05

Table 11: Serum Na^+, K^+, and Ca^{++} levels immediately before and after exposure to static magnetic field in group four (rats exposed to static magnetic field in day 1, 3, 7, and after 4 weeks) (Mean ± S.D).

Parameters	Number of Rats (n)	Mean ± S.D	P-value
Na^+ mmol/l			
Before exposure	10	137.10±2.64	
After exposure	10	136.30±4.59	0.63
K^+ mmol/l			
Before exposure	10	6.12±0.67	
After exposure	10	6.02±0.57	0.72
Ca^{++} mg/dl			
Before exposure	10	9.85±0.15	
After exposure	10	9.80±0.18	0.52

Table 12: Serum Na^+, K^+, and Ca^{++} levels in group four (rats exposed to static magnetic field in day 1, 3, 7, and after 4 weeks) compared to the initial finding of the experimental group (Mean ± S.D).

Parameters	Number of Rats (n)	Mean ± S.D	P-value
Na^+ mmol/l			
Control	43	141.65± 2.82	
After exposure	10	136.30±4.59	0.00*
K^+ mmol/l			
Control	43	5.12±0.52	
After exposure	10	6.02± 0.57	0.00*
Ca^{++} mg/dl			
Control	43	10.30±1.15	
After exposure	10	9.80±0.18	0.17

- P is significant at ≤ 0.05

Table 13: The histological findings of Albino rat's vital organs after exposures to SMF.

Exposures	Liver	Spleen	Kidney	Lung	Brain	Intestine	Pancreas	Muscle
Day 1	Necrosis, congestion	Hemorrhage, Presence of megakaryocytes	Congestion, degeneration, Hemorrhage, Necrosis, Segmentation of glomeruli	Congestion, emphysema	Congestion, vacuolation	Congestion, Sloughing of epithelial villi	Degeneration, Pyknotic nuclei presence.	Congestion, Degeneration, Hemorrhage
Day 3	Complete necrosis, hemorrhage	Hemorrhage	Necrosis, congestion, Degeneration, Segmentation of glomeruli	Emphysema	Congestion, vacuolation, Severe gliosis	Sloughing of epithelial villi	-	Congestion, Degeneration
Day 7	Necrosis, Congestion, Degeneration, hemorrhage	Congestion, Hemorrhage, degeneration, Giant cell presence	Congestion, degeneration, Hemorrhage, Necrosis, vacuolation, Segmentation of glomeruli	Congestion, Hemorrhage	Congestion, vacuolation, Degeneration	Sloughing of epithelial villi	-	Degeneration, Congestion
After 4 weeks	Necrosis, Pyknotic nuclei presence.	Hemorrhage, Degeneration, Presence of megakaryocytes	Necrosis, Degeneration, Vacuolation	Hemorrhage, Congestion, Emphysema	Congestion, vacuolation	Sloughing of epithelial villi	-	Degeneration

Table 14: The percentage of the affected rats.

Effects	Liver	Spleen	Kidney	Lung	Brain	Intestine	Pancreas	Muscle
Congestion	23.3%	11.6%	32.5%	32.5%	62.8%	11.6%	-	46.5%
Hemorrhage	20.9%	55.8%	20.9%	20.9%	-	-	-	11.6%
Vacuolation	-	-	23.2%	-	60.5%	-	-	-
Degeneration	9.3%	32.6%	83.7%	-	20.9%	-	11.6%	83.7%
Necrosis	51.2%	-	86.0%	-	-	-	-	-
Emphysema	-	-	-	41.8%	-	-	-	-
Sloughing of epithelial villi	-	-	-	-	-	51.1%	-	-
Gliosis	-	-	-	-	18.6%	-	-	-
Pyknotic nuclei presence.	11.6%		-	-	-	-	11.6%	-
Presence of megakaryocytes	-	34.9%	-	-	-	-	-	-
Segmentation of glomeruli	-	-	46.5%	-	-	-	-	-
Presence of giant cells	-	20.9%	-	-	-	-	-	-

Electrolyte results:

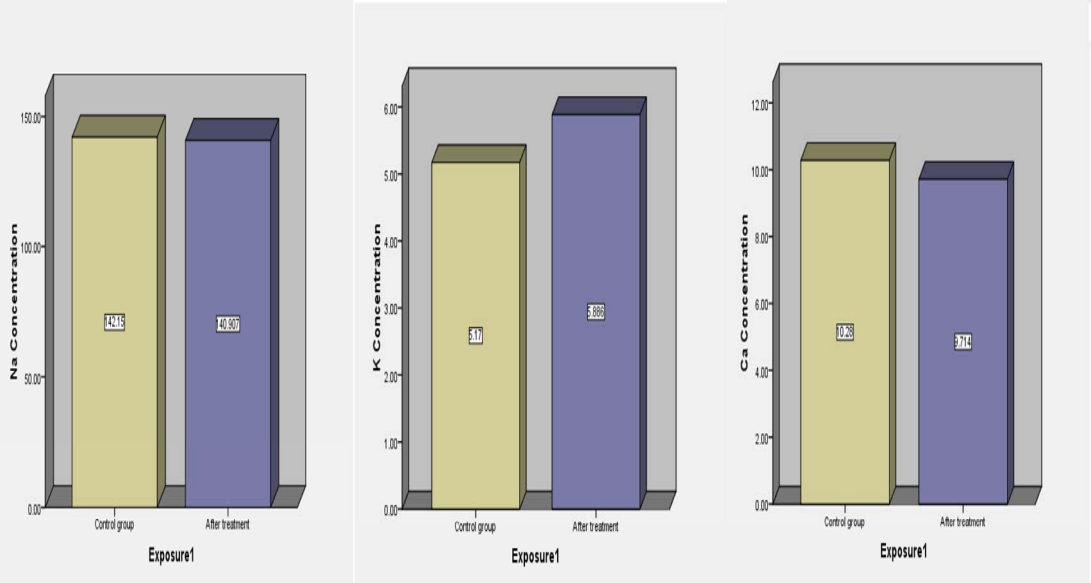

Figure 1 serum Na^{+}, K^{+}, and Ca^{++} levels in group one compared to control.

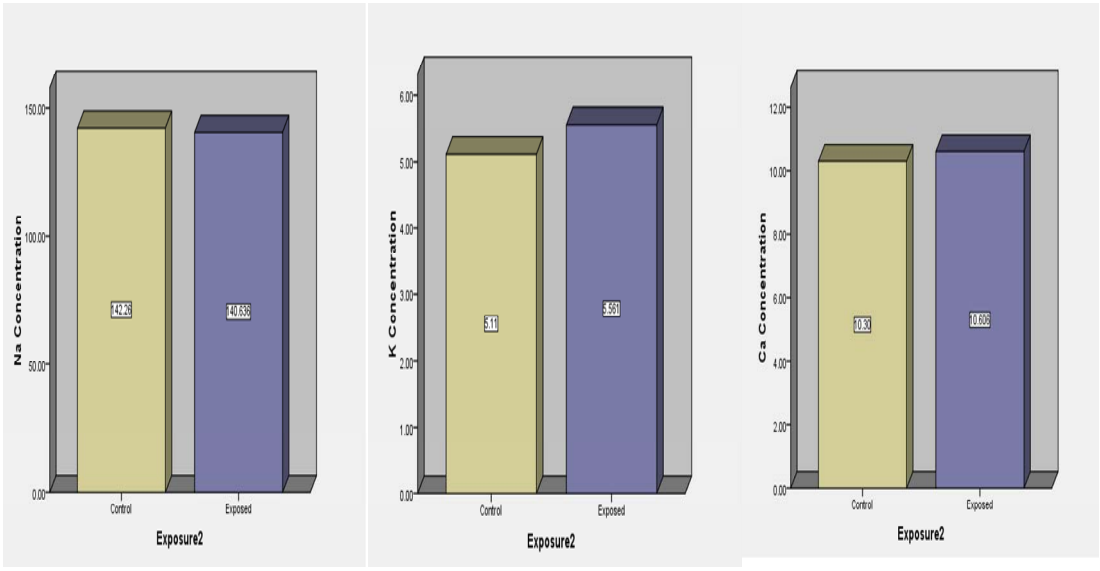

Figure 2 serum Na^{+}, K^{+}, and Ca^{++} levels in group two compared to control.

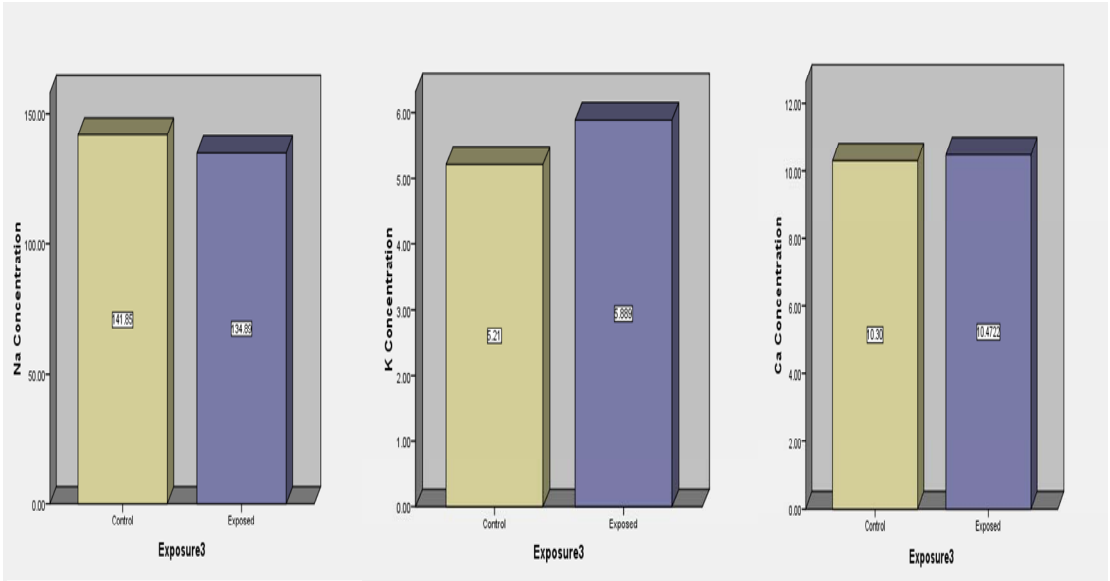

Figure 3 serum Na^{+}, K^{+}, and Ca^{++} levels in group three compared to control.

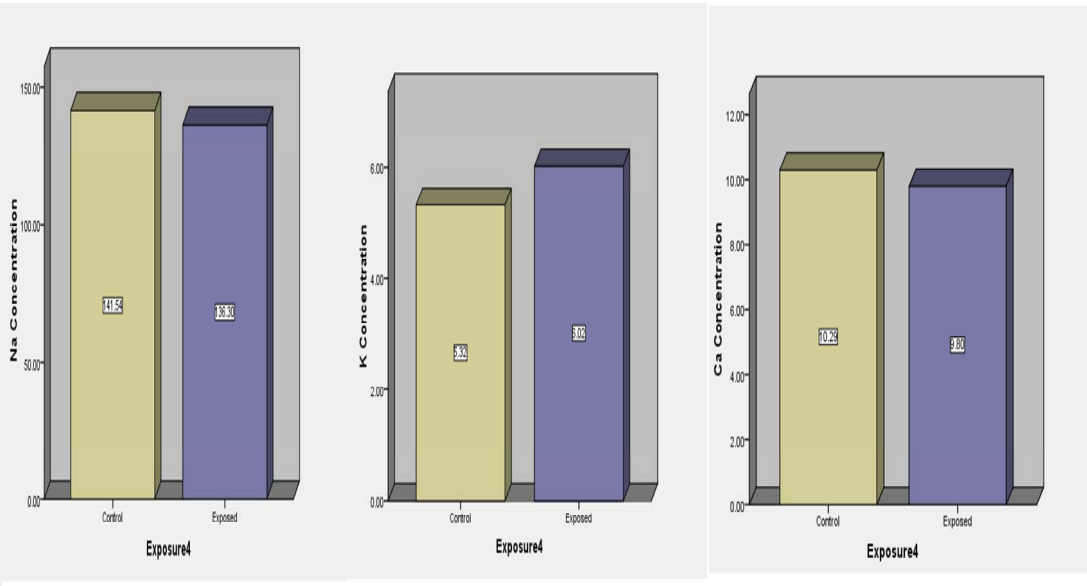

Figure 4 serum Na^{+}, K^{+}, and Ca^{++} levels in group four compared to control.

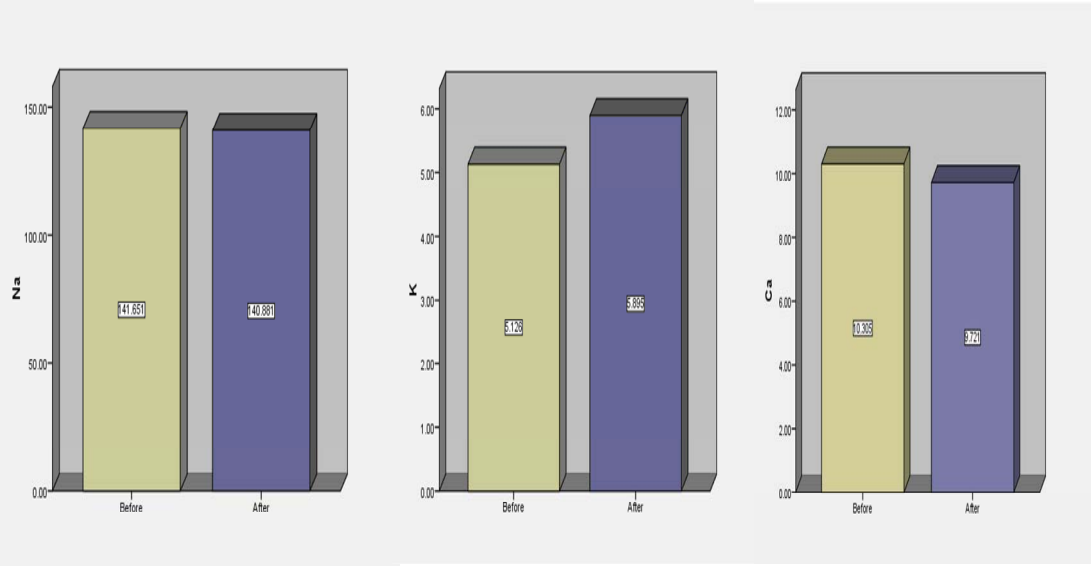

Figure 5 serum Na^{+}, K^{+}, and Ca^{++} levels in group one compared to the initial finding of the experimental group.

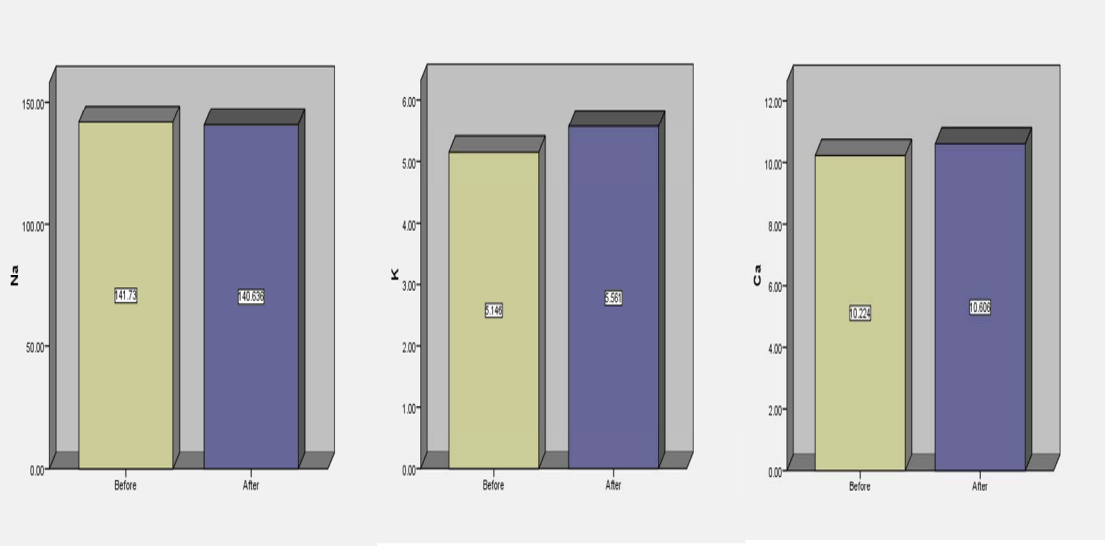

Figure 5 serum Na^{+}, K^{+}, and Ca^{++} levels in group one compared to the initial finding of the experimental group.

The following pictures show the histological findings in vital organs of the Albino rat's after exposure to SMF:

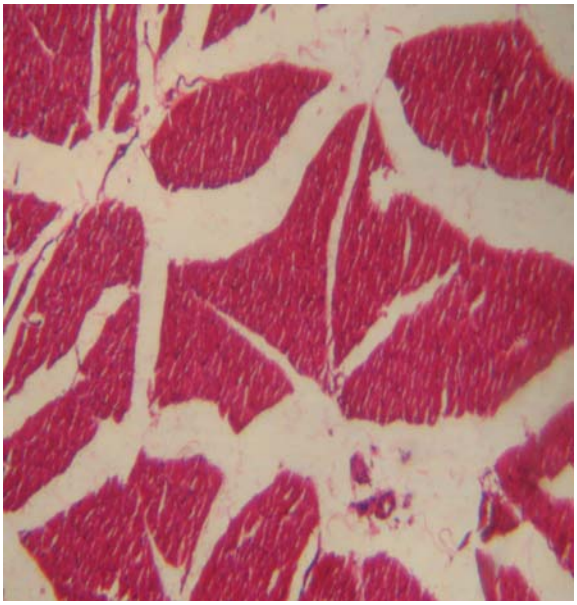

Figure 1 Normal muscle.

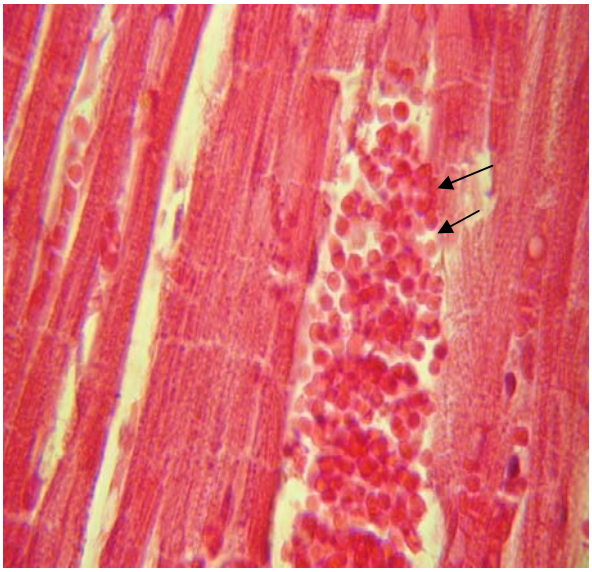

Figure 2 Degeneration of muscle fiber.

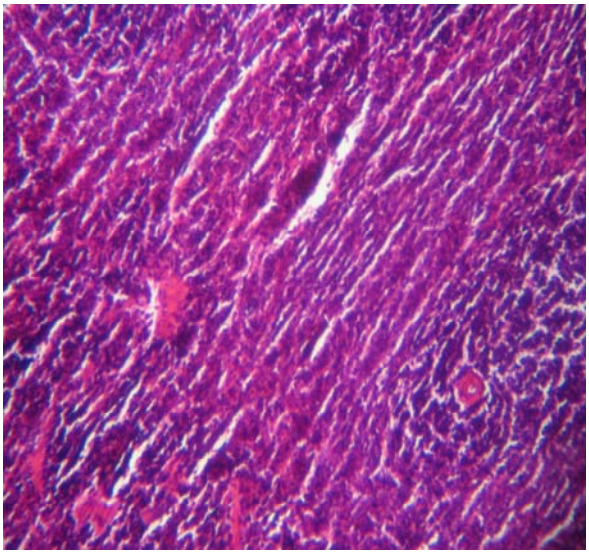

Figure 3 Normal spleen.

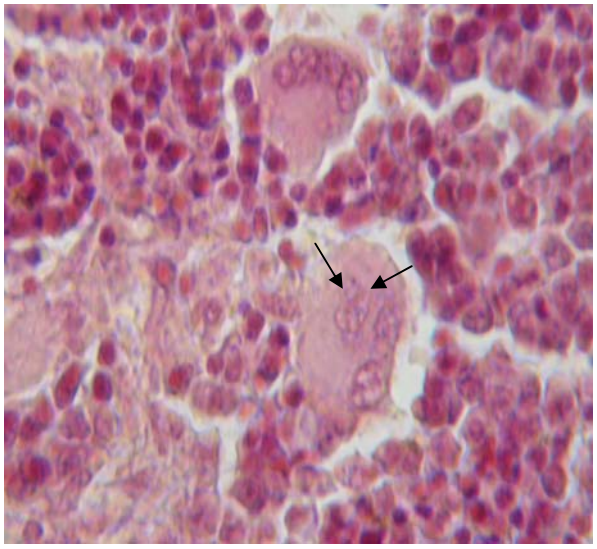

Figure 4 Megakaryocytes in spleen.

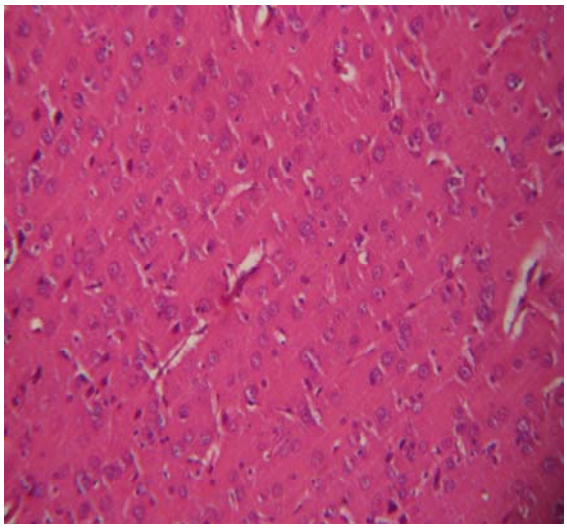

Figure 5 Normal brain

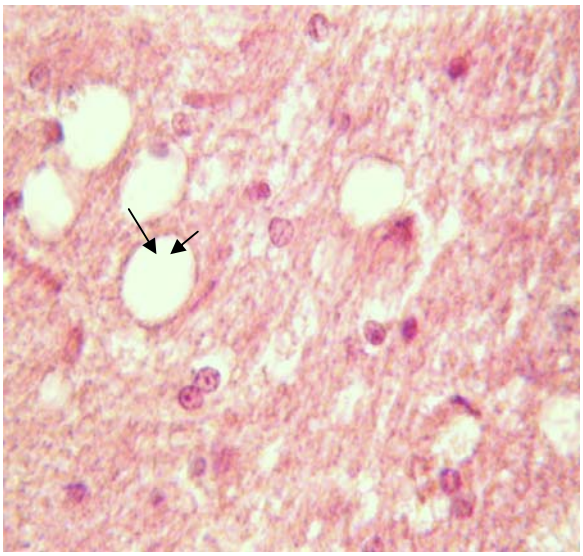

Figure 5 Vacuolation and degeneration in brain.

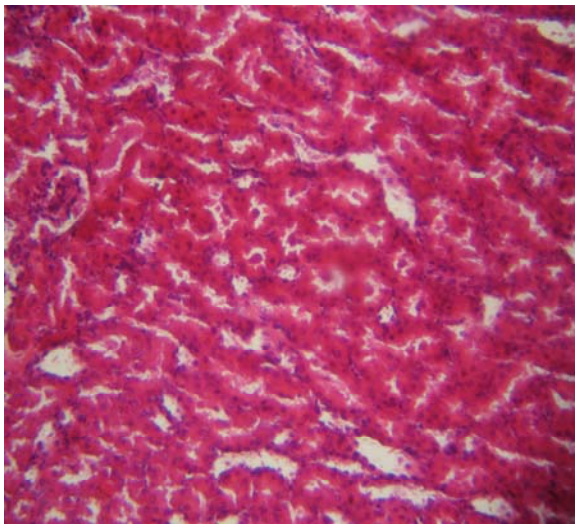

Figure 7 Normal kidney.

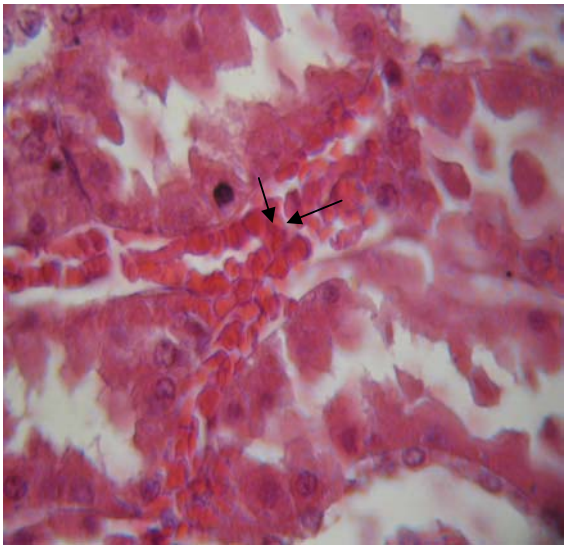

Figure 8 Congestion and hemorrhage of renal medulla and cortex.

Chapter Four

4. Discussion, Conclusion, and Recommendations

4.1 Discussion:

Serum electrolytes:

Due to the recent developments in electronic technologies, daily exposure to strong static magnetic field (SMF) is increasing. In particular is the increasing use of magnetic resonance imaging (MRI) for medical diagnoses. The intensity of SMF used at MRI due to development of MRI systems is increasing. Such strong-SMF exposure systems have great potential to improve medical and research applications (47).

Based on information available in the literature, the Center for Devices and Radiological Health suggested that in case of diagnostic magnetic resonance applications exposure to SMF must not exceed 2 T (20).

This was also the recommendation of the Federal Health Office; they added that patients imaged in MRI facility should not be exposed to SMF exceeding 2 T. If patients are to be re-exposed to a field higher than two T, they should be monitored for cardiac and circulatory functions (20).

On the other hand, the National Radiological Protection Board recommended that for people (patients and volunteers) exposed to the imaging process, the SMF should not exceed 2.5 T for the whole or a substantial portion of the body (20).

The interaction of magnetic fields with biological tissues can be characterized as electrodynamic or megnetomechanical in nature. The electrodynamic interaction originates from the interaction of magnetic field with electrolyte flows, leading to induction of electrical potential and currents (20)

Increased magnetic field activity in the environment of animals and humans disturbs many physiological processes in the body. Some disturbances caused by magnetic field influence are due to the reported change in K^+ content in the body fluids and organs. The hitherto studies

indicated a change in Na^+ and K^+ concentration in the arterial blood, urine, liver and kidneys. However, the results have been so far controversial (25).

In this study the obtained data showed that exposure of rats to 1.5 T SMF produced alteration in electrolytes concentration namely increase in potassium concentration and decrease in sodium concentration in the four days of the experiment. Our data are consistent with the finding of Gerasimova and Nakhil'nitskaia (28). They observed an increase in K^+ concentration during an hour exposure and a decrease in Na^+ concentration during a three-hour exposure to 4500 oersted CMF in rats.

Schober et al (29) observed the same findings. They studied the influence of weak magnetic fields on female white mice electrolytes balance. A 10 Hz rectangular field have been applied because of its similarity to some biologic rhythms and because some technical environments tend to produce similar type of field. The changes of electrolyte balance were measured after one and seven days after exposure of the animals. They found that a one-day exposure to a 10 Hz rectangular field significantly lowered the Na^+ and increased K^+ levels. Almost reversed results were obtained after seven days. This might indicate overcompensation, after recovery.

Similarly Banaszkiewic et al (27) found that exposure to 10 mT magnetic field combined with infrared laser radiation for 10 days, 10 minutes once a day induced hyperkalaemia and hyponatremia in rats.

Serafin et al (26) had reported similar finding on human. They observed a significant increase in the concentration of K^+ in patients who are at risk of coronary heart disease when exposed to pulsed magnetic fields (maximum intensity of 0.07 mT) for 24 days, 8 minutes twice a day.

Gorczynska and wegrzynowicz (25) observed a different finding in guinea pigs. They found significant increase in Na^+ and decrease in Cl^- concentration in serum of guinea pigs exposed to magnetic field 0.005 T-0.3 T for six weeks 1 hour a day, 7 days a week, and no change in serum K^+.

One of the suggested mechanism by which SMF induce hyperkalaemia and hyponatrenia is a decrease in Na^+-K^+-ATP-ase activity under the influence of SMF (25).

Na^+-K^+-ATP-ase transports three Na^+ ions outside and simultaneously two K^+ ions inside across the cell membrane. In this way, each Na^+-K^+ pump transfers 9000 Na^+ ions outside and 6000 K^+ ions inside the cell in one minute (17). However when the activity of the Na^+-K^+ pump decrease this spontaneously induce hyperkalaemia and hyponatrenia.

Another study recognized that formed elements of blood were affected by the shear stresses resulting from the magnetic field. It showed that on red blood cells shear stress affect their cell membrane, and the cell can experience sub-lethal damage, as well as destruction (20). They suggested that the increase in potassium concentration might be due to this hemolysis.

In addition, the effect of SMF on electrolytes may be by its effect on cell membrane channels. The mechanism suggested to explain these effects is based on the diamagnetic anisotropic properties of membrane phospholipids. It is proposed that reorientation of these molecules during moderate SMF exposure will result in the deformation of imbedded ion channels, thereby altering their activation kinetics. Most of the reported moderate SMF effects may be based on alterations in membrane calcium ion. Additional studies have demonstrated that sodium channels are similarly affected by SMF, although to a lesser degree. These findings support the view that moderate SMF effects on biological membranes represent a general phenomenon, with some channels being more susceptible than others to membrane deformation (48).

Petrov and Martinac (49) also suggested that the effects of SMF on the channels might result from changes in physical properties of the lipid bilayer due to diamagnetic anisotropy of phospholipids molecules. Consequently, cooperative superdiamagnetism of phospholipid molecules under the influence of SMF could cause displacement of gadolinium ion (Gd^{+++}), which is a well-known channel blocker from the membrane bilayer and thus remove the channel block.

Typical responses to SMF include an overall reduction in channel activity or an increased likelihood of channels becoming "trapped open" in sub-conducting states following exposure to SMF. Generally, channel activity showed slow or limited recovery following removal of the magnetic field and responses to the magnetic field were often reduced or abolished upon subsequent exposures (50).

In this study serum Ca^{++} concentration fluctuated between an increase in day 3 of exposure to 1.5 T SMF and a decrease in day 1 and After 4 weeks from day seven of exposure. Tenuzzo et al (30) studied the bio-effects induced by exposure to 6-mT static magnetic field on primary cultures of human lymphocytes, and mice thymocytes. They found an increase of intracellular Ca^{++} ions because of 6-mT SMF exposure.

On the other hand Schober et al (29) found significant hypocalcaemia in female white mice after 50 Hz sinusoidal and 50 Hz rectangular magnetic field exposure.

Electromagnetic fields had been reported to cause a variety of biological effects. It had been hypothesized that many of these phenomena are mediated by a primary effect on the concentration of cytosolic free calcium [Ca2+]i (31).

Carson et al (31) investigated the effects of exposure to electromagnetic fields on cytosolic calcium concentration [Ca2+]i in cell cultures of HL-60 cells. They exposed the HL-60 cells to a radiofrequency electromagnetic field, a static magnetic field, and a time-varying magnetic field, which were generated by a magnetic resonance imaging (MRI) unit. They found that a 23-min exposure to all three fields, in combination, induced a significant increase in [Ca2+]i.

On the other hand, Aldinucci et al (32) investigated the effect of combining static electromagnetic field (EMF) at a flux density of 4.75 T together with pulsed EMF at a flux density of 0.7 mT on Ca^{++} movement in human lymphocytes. Exposing the lymphocytes to those fields for 1 hour lead to a clear increase in [Ca2+]i.

Tissues histology:

The microscopic changes observed in the rats in all groups were similar in nature but varied in extent and severity between the rats in the same groups and they are observed from the 1st exposure.

The histology of the liver showed that in 23.3% congestion was present, 20.9% were affected by hemorrhage, 9.3% were affected by degeneration, 51.2% were affected by necrosis, and in 11.6% Pyknotic nuclei were present (Table 14).

In the spleen, the main effect was hemorrhage in 55.8%, in 34.9% megakaryocytes were present, 32.6% were affected by degeneration, and in 20.9% giant cells were present. Moreover, 11.6% were affected by congestion (Table 14)

Regarding the histology of the kidney 32.5% were affected by congestion, 20.9% were affected by hemorrhage, 23.2% were affected by vacuolation, 83.7% were affected by degeneration, 86.0% were affected by necrosis, and 46.5% were affected by segmentation of glomeruli (Table 14).

Emphysema was present in the lung in 41.8%, 32.5% were affected by congestion, and 20.9% were affected by hemorrhage (Table 14).

In the brain 62.8% were affected by congestion, 60.5% were affected by vacuolation, 20.9% were affected by degeneration, and 18.6% were affected by severe gliosis (Table 14).

Sloughing of epithelial villi was the main effect in the intestine, it affect 51.1%, and 11.6% were affected by congestion (Table 14).

In the pancreas 11.6% were affected by degeneration, and in 11.6% Pyknotic nuclei were present (Table 14).

In the muscle, degeneration was noticed in 83.7%, 46.5% were affected by congestion, and 11.6% were affected by hemorrhage (Table 14).

Similar finding had also been reported by Caroline (20), she found that there were severe hemorrhage in cardiac muscle, kidney, and liver, center lobular necrosis and congestion in the liver, and congestion of the blood vessels in bone marrow in Albino rats repeatedly exposed to 1.5 T SMF.

Lai and Singh (39) studied the effect of SMF on brain cells. They found an increase in DNA single- and double-strand breaks in rat's brain cells exposed to a 60-Hz sinusoidal magnetic field at intensities of 0.1-0.5 mT for 2 hr, 24 hr, and 48 hr. They also reported that the effect was cumulative.

Svedenstal et al (38) conducted another study on brain cells. They observed a significantly extended DNA migration on brain cells of mice exposed continuously to 50 Hz, 0.5 mT magnetic fields for 2 hrs, 14 days. These changes indicated that magnetic fields might have genotoxic effects in brain cells.

Buemi et al (41) studied the effect of SMF on renal cells from rats. They found a gradual increase in cells with a necrotic morphology in renal cells exposed to a 0.5 mT SMF after 2, 4 and 6 days of exposure. They suggested that SMF might have a nephropathogenic effect in the kidney.

Pacini et al (7) studied the effects of 0.2 T SMF generated by magnetic resonance tomography on a normal human neuronal cell culture. They observed that after 15 minutes exposure, cells showed dramatic changes of morphology, developing branched dendrites featuring synaptic buttons. Some modifications in the physiological functions of cells were also reported.

On the other hand Gorczynska and Wegrzynowicz (40) examined the morphology of cardiac muscle, skeletal muscles, kidneys, cerebellum and lung tissues in guinea pigs exposed to 0.005 T SMF for seven weeks, 1 hour a day, 7 days a week. They concluded that no morphological changes were

observed. This can be due to the low intensity of the static magnetic field 0.005 T compared to that used in this study 1.5 T.

The suggested mechanism by which SMF causes cellular damage can be evaluated by determination of the frequency of micronucleus formation. The presence or absence of such micronuclei can confirm whether a particular treatment causes cellular damage (37).

lkhata et al (51) studied the cytogenetic effects on the mouse bone marrow cells when exposed to 3 T and 4.7 T static magnetic fields, they found that micronuclei frequency was significantly increased and it was dose dependent.

Miyakoshi (37) found that the frequency of micronucleus formation increases significantly when certain treatments (e.g., X-irradiation) are given prior to exposure to a 10 T SMF. Takehisa et al (47) confirmed the same finding. They found that exposure to SMF caused a statistically significant increase in micronucleus frequency after 4-Gray doses of x-ray irradiation.

Free radicals are also incriminated as factor for cell damages resulting from magnetic field exposure. Biological free radicals are most commonly oxygen or nitrogen based with an unpaired electron, leading to the terms reactive oxygen species (ROS) or reactive nitrogen species (RNS). The free radical generation resulting from exposure to SMF can lead to apoptosis/necrosis of cell (52).

Free radicals are supposed to be involved in harmful reactions in biological systems, thus any effect that might increase their reactivity or concentration could produce or enhance harmful effect. According to the most accepted theory, the magnetic field splits the radical pairs into two energy levels; this increases the radical's pairs that escape the recombination reaction (20). Another theory suggested that magnetic field increases the concentration and/or lifetime of free radicals that escape from the radical pair so that the critical radical concentration needed to initiate membrane damage and cause cell lyses is reached sooner (53).

4.2 Conclusion:

The study was designed to assess the effects of SMF of range used in MRI machine (1.5 T) on serum Na^{+}, K^{+}, Ca^{++} concentrations and some tissues histology in rats. The followings were the major findings:

-Increase in serum K^{+} concentration.

-Decrease in serum Na^{+} concentration.

-Fluctuation in serum Ca^{++} concentration.

The histology of the vital organs of rats exposed to SMF of range used in MRI machine (1.5 T) showed:

-Necrosis, hemorrhage, and congestion of liver cells.

-Congestion and hemorrhage of renal medulla and cortex.

-Congestion, hemorrhage, and emphysema in lungs.

-Congestion and sloughing of epithelial vlilli in intestine.

-Congestion and hemorrhage in spleen.

-Vaculolation, and degeneration of brain cells.

-Congestion and degeneration of muscle fiber.

-Degeneration of pancreas.

This might increase health and environmental concern on the deleterious effects of SMF on human beings. Further studies to confirm these findings in human and to explain the mechanism of these changes are needed.

4.3 Recommendations:

1/ There is a clear need for additional studies for SMF in the areas, in which the available information is either in adequate or contradictory.

A/ Studies on functional alterations in the skin, and cardiovascular system, where magnetic field interactions have previously been observed are needed, particular emphasis should be placed on the effects of long term exposures or repeated exposure.

B/ Studies on the cell membrane function under influence of SMF.

C/ Studies on the effects of exposure to combined SMF and RF on serum electrolytes.

D/ Hematology and histology studies are needed on different experimental animals and animal's responses to SMF above 2T, as proposed for use in MR spectroscopy as repeated exposure and in long exposure time.

2/ Special care must be taken for patients with heart diseases or nervous system abnormalities. On exposure to SMF a sudden changes of Na^{+}, K^{+}, and Ca^{++} levels might be a serious complication.

3/ The knowledge of magnetic resonance imaging systems safety can not only help guide the future design of these instruments, but also affect the selection of the technical procedures in order to ensure safe, efficacious and efficient system operation.

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Appendix:

Many photographs were taken for different rat organs under the microscope; the following pictures show the histological findings in vital organs of the Albino rat's after exposure to SMF:

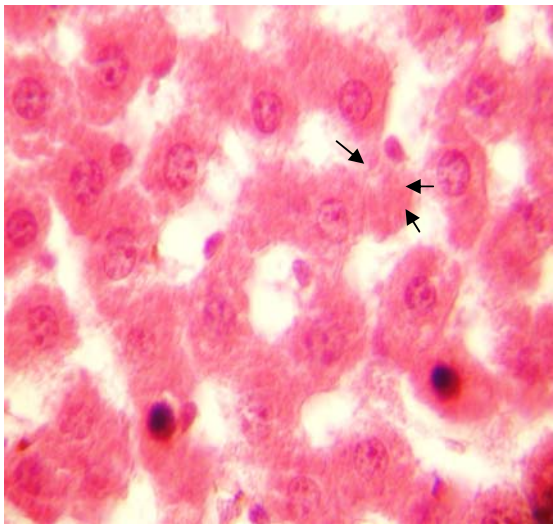

Figure (5) Shrinking of hepatocytes in the liver.

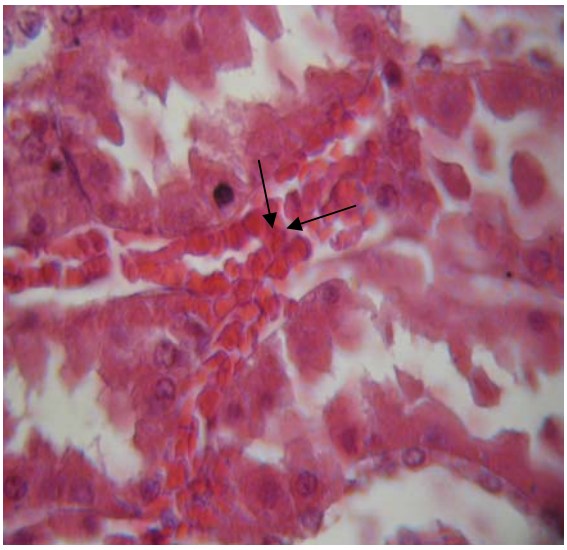

Figure (6) Congestion and hemorrhage of renal medulla and cortex.

Figure (7) Vacuolated glomeruli in kidney

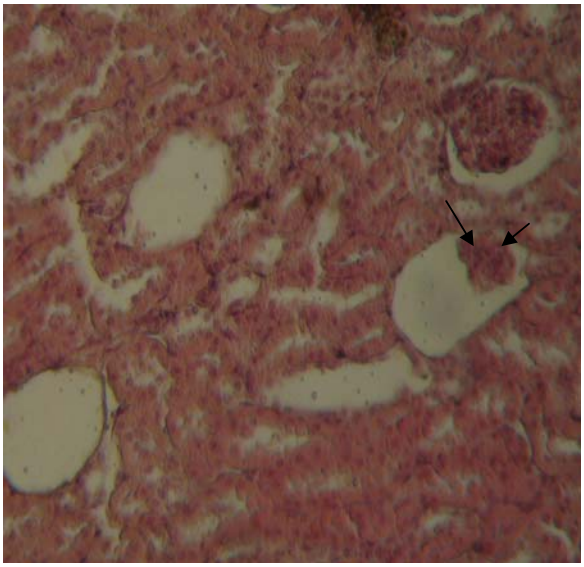

Figure (8) Degeneration and necrosis in renal cortex

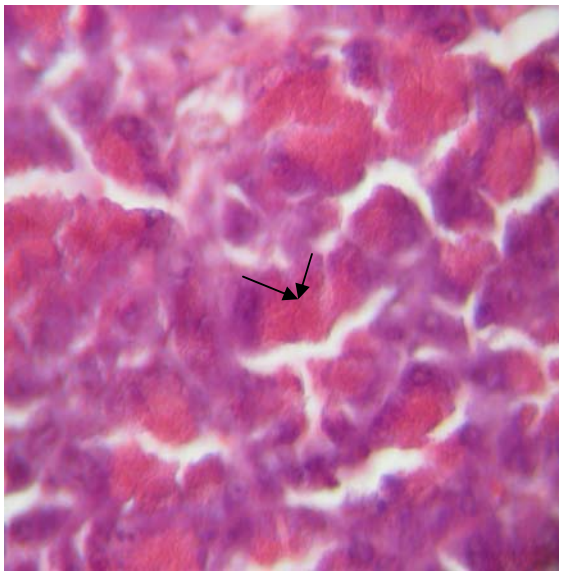

Figure (9) Necrosis and deposition of eosinophillic granules in pancreatic tissues.

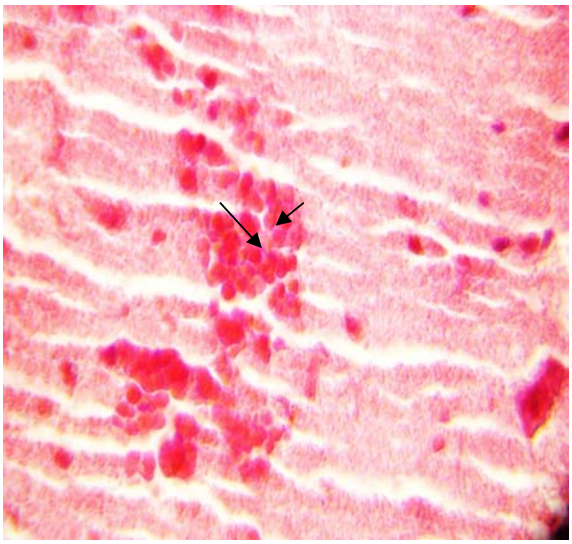

Figure (10) Hemorrhage in muscles

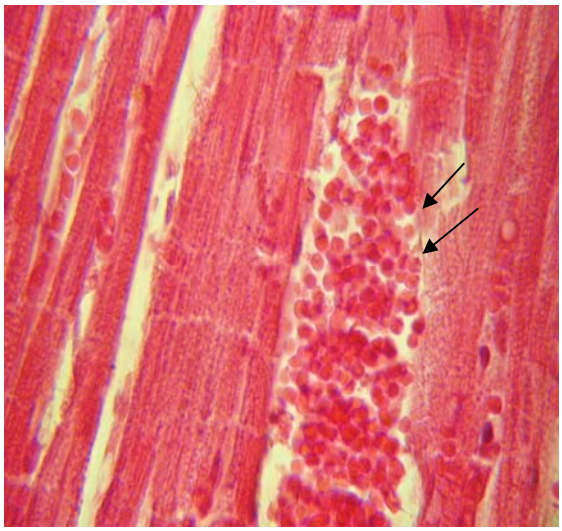

Figure (11) Degeneration of muscle fiber.

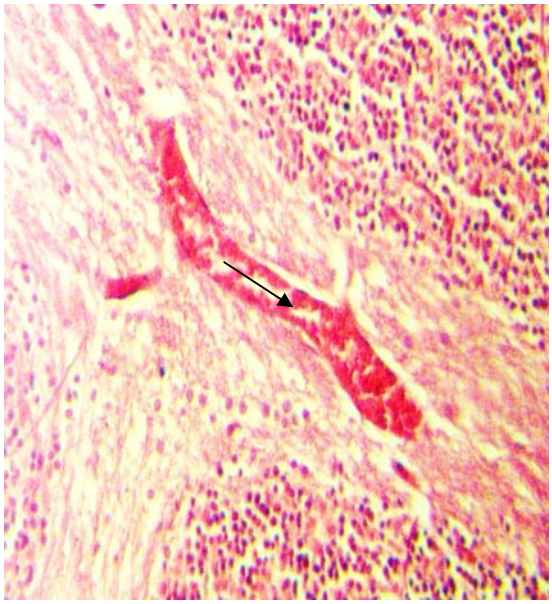

Figure (12) Congestion of cerebral blood vessels.

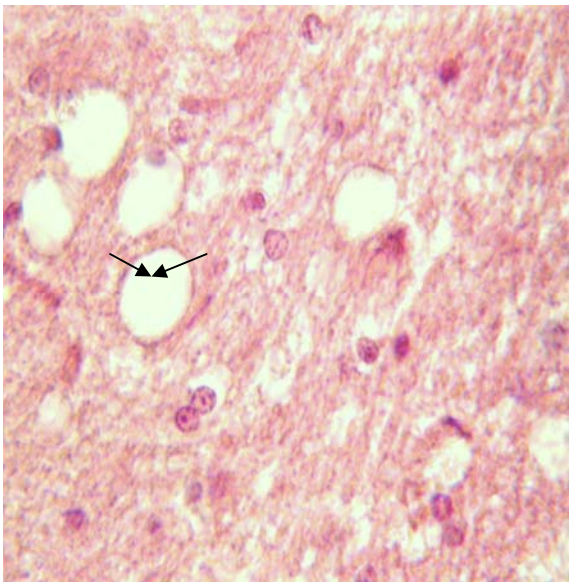

Figure (13) Vacuolation and degeneration in brain.

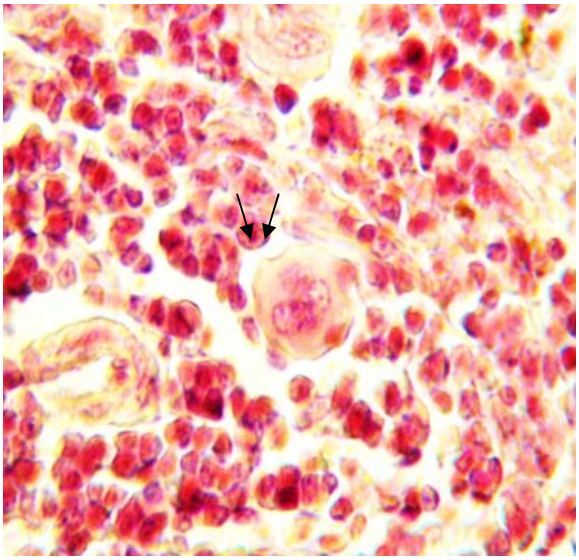

Figure (14) Haemosidren deposits in spleen.

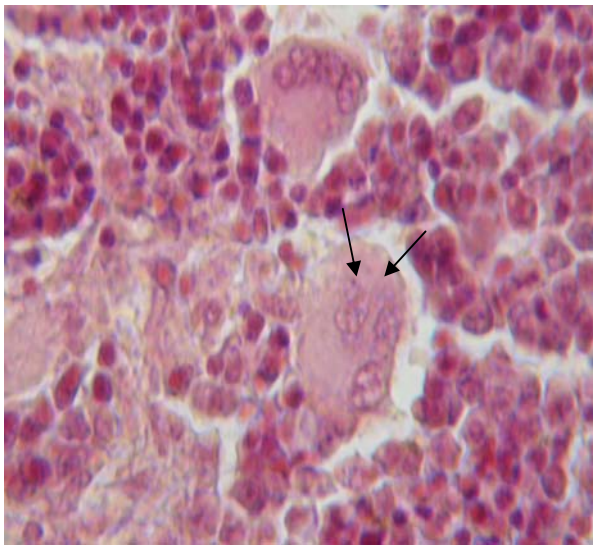

Figure (15) Megakaryocytes in spleen.

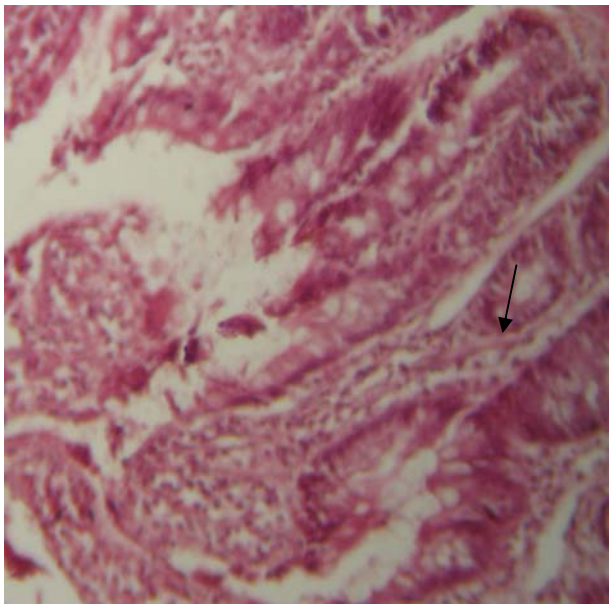

Figure (16) Desquamation of lining epithelium in intestine.

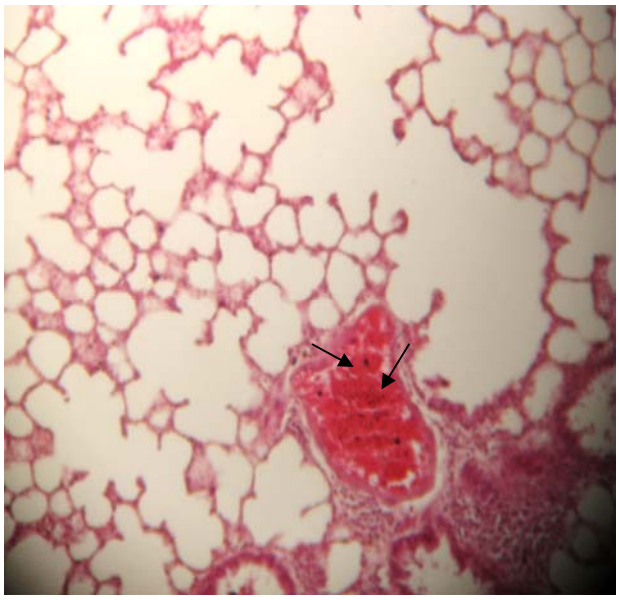

Figure (17) Congestion of alveolar capillaries and emphysema in lung.

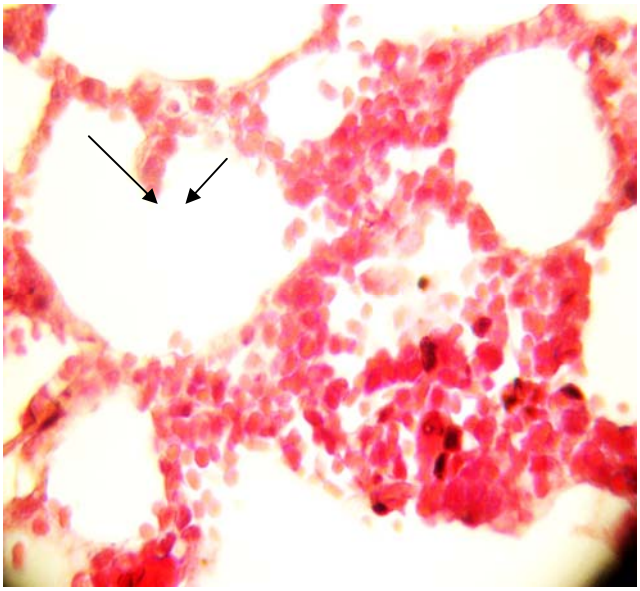

Figure (18) Emphysema and hemorrhage in lung.